



**Aerospace  
Systems Division**

*R. Miley*

|                   |              |
|-------------------|--------------|
| NO.               | REV. NO.     |
| ATM-764           |              |
| PAGE <u>1</u>     | OF <u>42</u> |
| DATE 15 July 1968 |              |

**FINAL REPORT -**

**Thermal Analysis and Correlation  
of ALSEP Prototype Cask Cooling Tests**

Prepared by: *B. Nordquist*  
B. Nordquist

Approved by: *J. McNaughton*  
J. McNaughton



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |              |
|-------------------|--------------|
| NO.               | REV. NO.     |
| ATM-764           |              |
| PAGE <u>2</u>     | OF <u>42</u> |
| DATE 15 July 1968 |              |

INDEX

|   | <u>Page</u> |
|---|-------------|
| 1.0 INTRODUCTION  | 5           |
| 2.0 THERMAL ANALYSIS AND CORRELATION                          | 14          |
| 3.0 CONCLUSIONS   | 29          |
| 4.0 DISCUSSION  | 31          |
| 4.1 ALSEP RTG CASK COOLING SYSTEM INTERFACE<br>CONSIDERATIONS | 31          |

LIST OF FIGURES

| <u>No.</u> | <u>Title</u>  |    |
|------------|---|----|
| 1.1        | Proposed Location of ALSEP Cask Cooling Structure                   | 6  |
| 1.2        | Cask Cooling Conical Nozzle   | 7  |
| 1.3        | Cask Cooling Plugged Nozzle   | 8  |
| 1.4        | Prototype Conical Nozzle Configuration Inside SLA/LM Canister       | 9  |
| 1.5        | SLA/LM Canister Used for Prototype Cask Cooling and T/V Tests       | 10 |
| 1.6        | Prototype Cask and Conical Nozzle Configuration (Viewed From Above) | 11 |
| 1.7        | RTG Cask Cooling Nozzle Locations for BxA Prototype Test Program    | 12 |
| 1.8        | Proposed RTG Cask Cooling Interface Configuration                   | 13 |



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

| NO.               | REV. NO. |
|-------------------|----------|
| ATM-764           |          |
| PAGE 3            | OF 42    |
| DATE 15 July 1968 |          |

LIST OF FIGURES (continued)

|   | Page |
|---|------|
| 2.1 Temperature Decay of a 130°F Jet Exhausting Into 75°F Air   | 18   |
| 2.2 On Pad Forced Cooling Test Cask Surface Temperature Results - 10 lb/min of 130°F Air, Run No. 1                         | 19   |
| 2.3 On Pad Forced Cooling Test Cask Surface Temperature Results - 17 lb/min of 130°F Air, Run No. 2                         | 20   |
| 2.4 On Pad Forced Cooling Test Cask Surface Temperature Results - 17 lb/min of 75°F Air, Run No. 3                          | 21   |
| 2.5 On Pad Forced Cooling Test Cask Surface Temperature Results - 17 lb/min of 130°F Air (Nozzle Offset to Right) Run No. 5 | 22   |
| 2.6 On Pad Forced Cooling Test Cask Surface Temperature Results - 17 lb/min of 130°F Air (Nozzle Offset to Left) Run No. 38 | 23   |
| 2.7 On Pad Forced Cooling Test Cask Surface Temperature Results - 22 lb/min of 130°F Air, Run No. 17                        | 24   |
| 2.8 On Pad Forced Cooling Test Cask Surface Temperature Results - 27 lb/min of 130°F Air, Run No. 19                        | 25   |
| 2.9 Downstream Jet Velocity for the Fuel Cask Located 2 Feet Above a 2.25 inch Diameter Nozzle                              | 28   |
| 2.10 GLFC Surface Transient Temperature Rise  | 30   |
| 4.1 Overlay of Nozzle Performance on MSFC IU Duct Performance   | 32   |
| 4.2 Physical Configuration of CSM/LEM/SLA - Block 11  | 34   |
| 4.3 Flow Temperature Decay  | 35   |
| 4.4 Jet Temperature Decay and Mass Entrainment  | 37   |
| 4.5 Recirculatory Flow Adiabatic Equilibrium Temperature  | 39   |



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                            |          |
|----------------------------|----------|
| NO.                        | REV. NO. |
| ATM-764                    |          |
| PAGE <u>4</u> OF <u>42</u> |          |
| DATE 15 July 1968          |          |

LIST OF TABLES

| <u>No.</u> | <u>Title</u>                                   | <u>Page</u> |
|------------|--|-------------|
| I          | Summary of Prototype Cask Cooling Test Results | 17          |
| REFERENCES |  | 42          |

## 1.0 INTRODUCTION

In November of 1967, the first RTG on-pad cask cooling tests were carried out in order to evaluate various cask cooling concepts and are reported in Bendix ALSEP Technical Memorandum ATM #763. The results of that test were highly satisfactory in that the cooling problem was found to be less critical than had been originally anticipated. That is, there was a considerable design latitude in the various cask cooling configurations which would hold the cask surface temperature below 300 °F with the suggested amount of cooling flow (20 - 50 pounds per minute). This information thereby allowed the prototype cooling system to be designed on the basis of minimal weight and interference problems - and with only secondary considerations given to the actual efficiency of the cooling system.

From an interference standpoint, a more remote placement of the nozzle was desirable in order to structurally mount the nozzle with the Saturn IV-B IU Panel 23, reference Figure 1.1. Therefore, the prototype tests were carried out with the nozzle at distances of 15, 24, and 36 inches below the cask and included several off-axis positions as well as the axially aligned cases. At those distances a conical nozzle (Figure 1.2) is more effective in cooling (and lighter) than a plugged nozzle (Figure 1.3). Thus only a few plugged nozzle tests were carried out in order to tie in the present test results with those of the previous test. The majority of testing was carried out with a conical nozzle having a 2.25 inch throat diameter. Also a 2.75 inch diameter nozzle was used to accommodate the higher mass flow rates of the test.

The actual test setup including the SLA/LM simulation canister is pictured in Figures 1.4 through 1.6. In Figures 1.7 and 1.8 the equivalent positioning of the cask cooling system inside the Saturn S IV-B is shown. Note that the nozzle positioning of Figure 1.7 was laid out to maintain the nozzles outside the LM withdrawal line. However, it was later determined that the withdrawal line could be modified to accommodate the conical nozzle at 24 inches below the cask. Thus the prototype test nozzle was repositioned to include testing at the 24 inch distance (Figure 1.7).

Just prior to the prototype test, information was received during the Cask Cooling Interface Meeting at MSFC on 12 March 1968 which indicated that there was a possibility that the IU flow rate might be substantially reduced during the pre-launch period when technicians would be working inside the SLA. The nominal value of the reduced cooling flow was estimated at a total of 110 pounds per minute to the IU duct. Consequently with the cooling nozzles of the prototype test, approximately 15 - 20 pounds per minute of the 110 pound per minute total would be available for cask cooling.

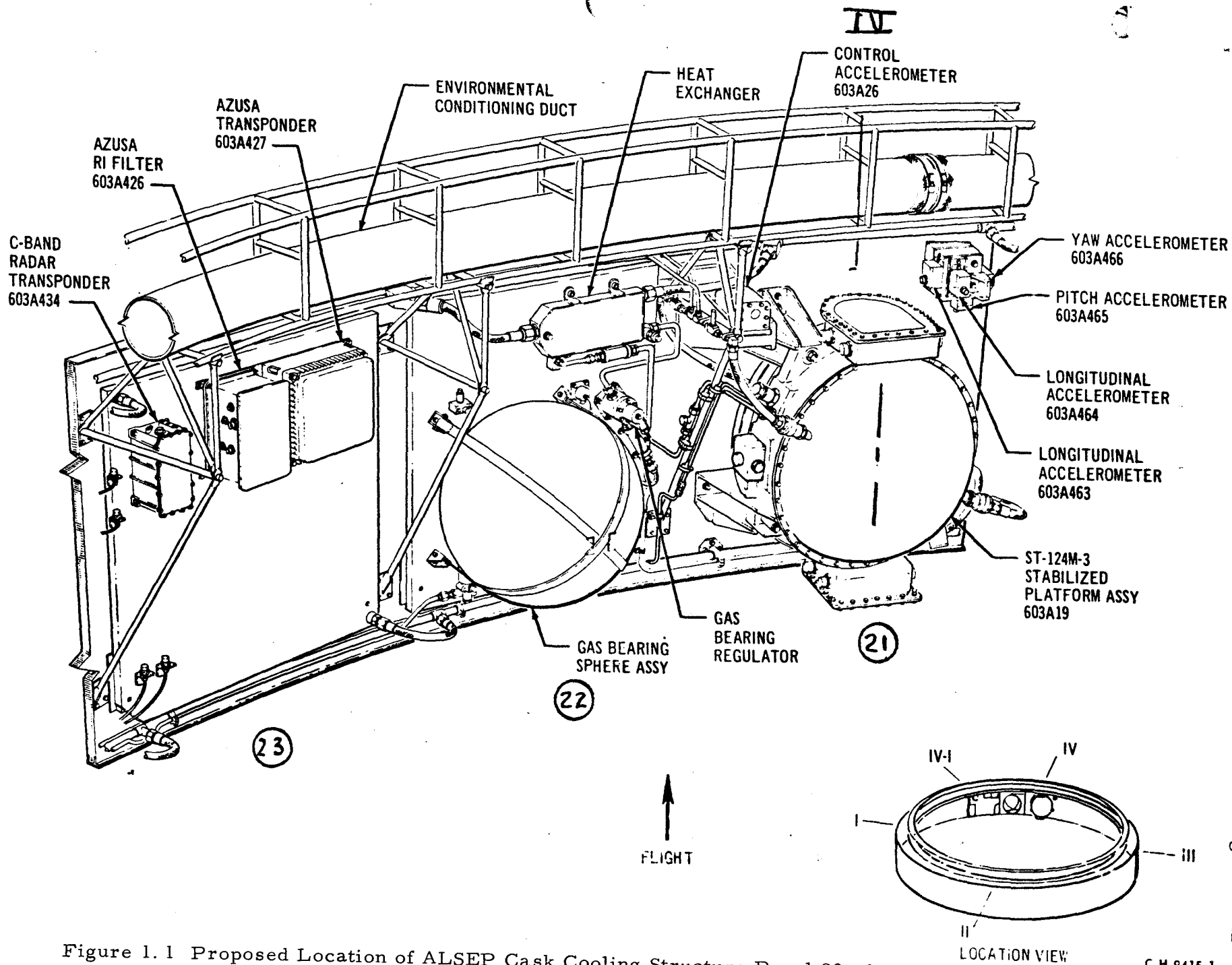
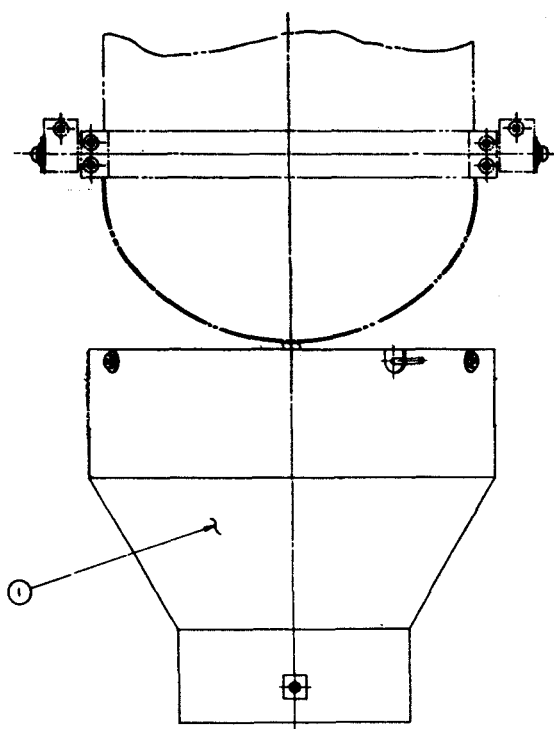


Figure 1.1 Proposed Location of ALSEP Cask Cooling Structure Panel 23 of Instrumentation Unit (I. U.)

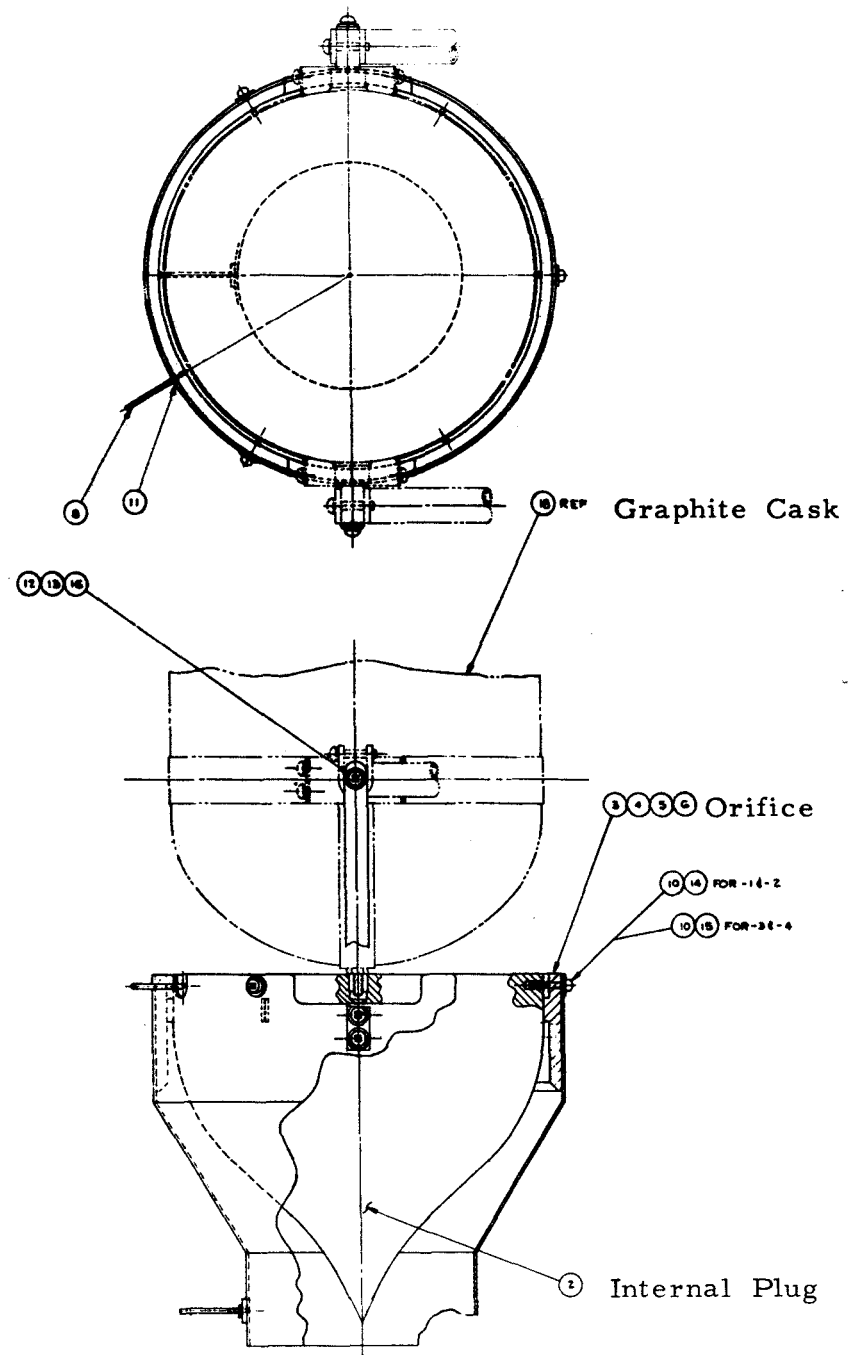


Outer Nozzle  
Housing



Cask Lower Trunnion

Figure 1.3 Cask Cooling Plugged Nozzle



Graphite Cask

Orifice

Internal Plug



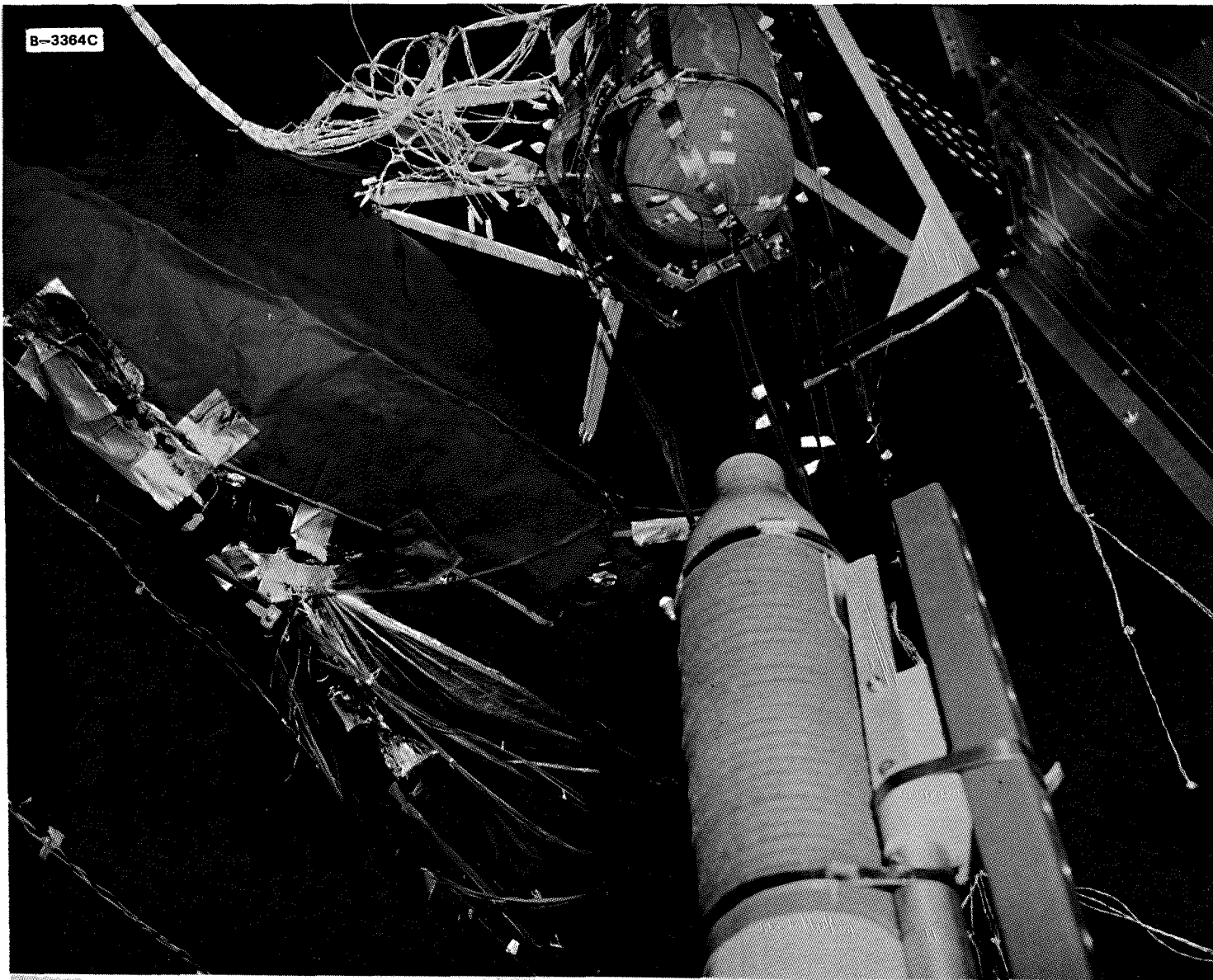


Figure 1.4 Prototype Conical Nozzle Configuration Inside SLA/LM Canister

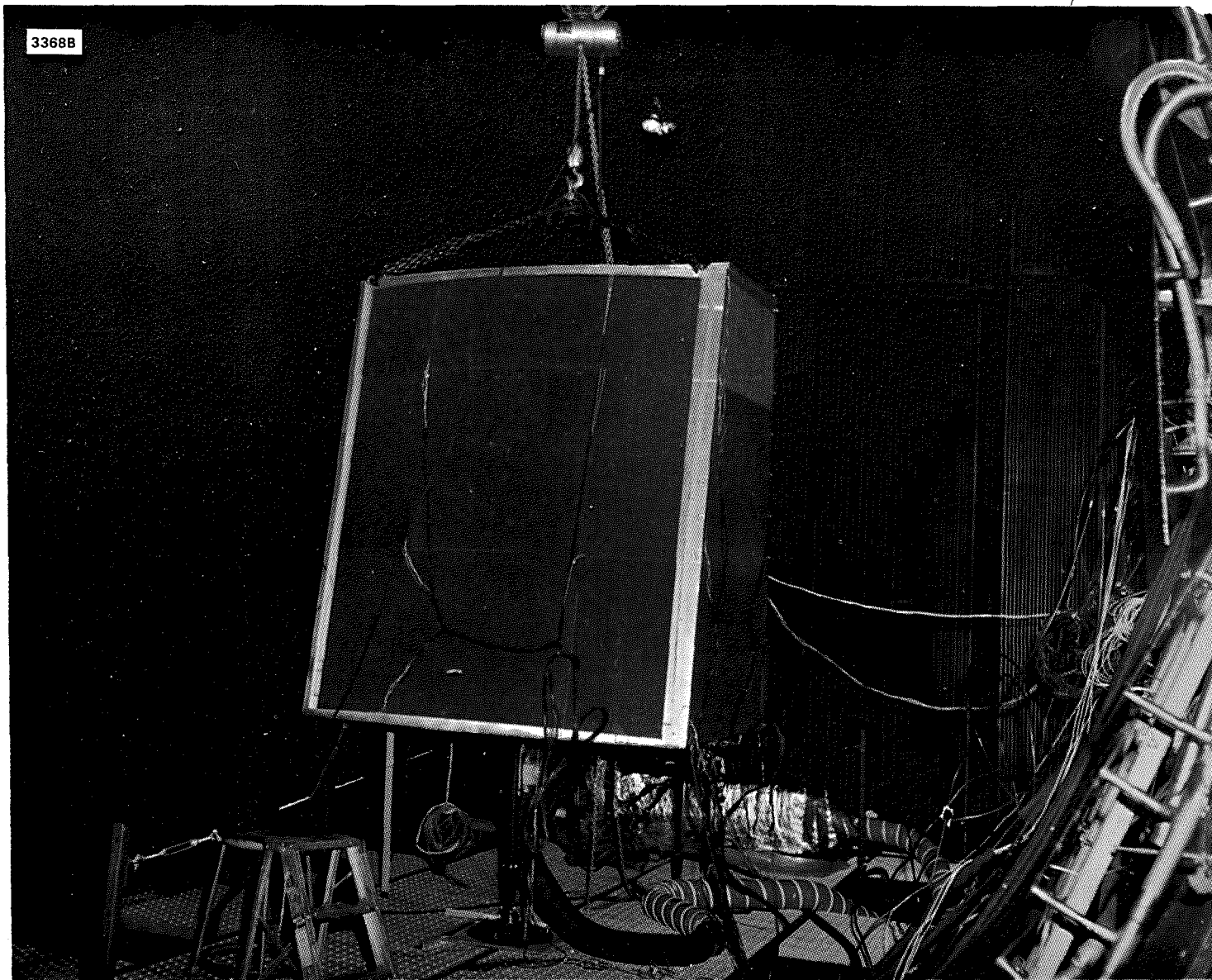


Figure 1.5 SLA/LM Canister Used for Cask Cooling and T/V Tests

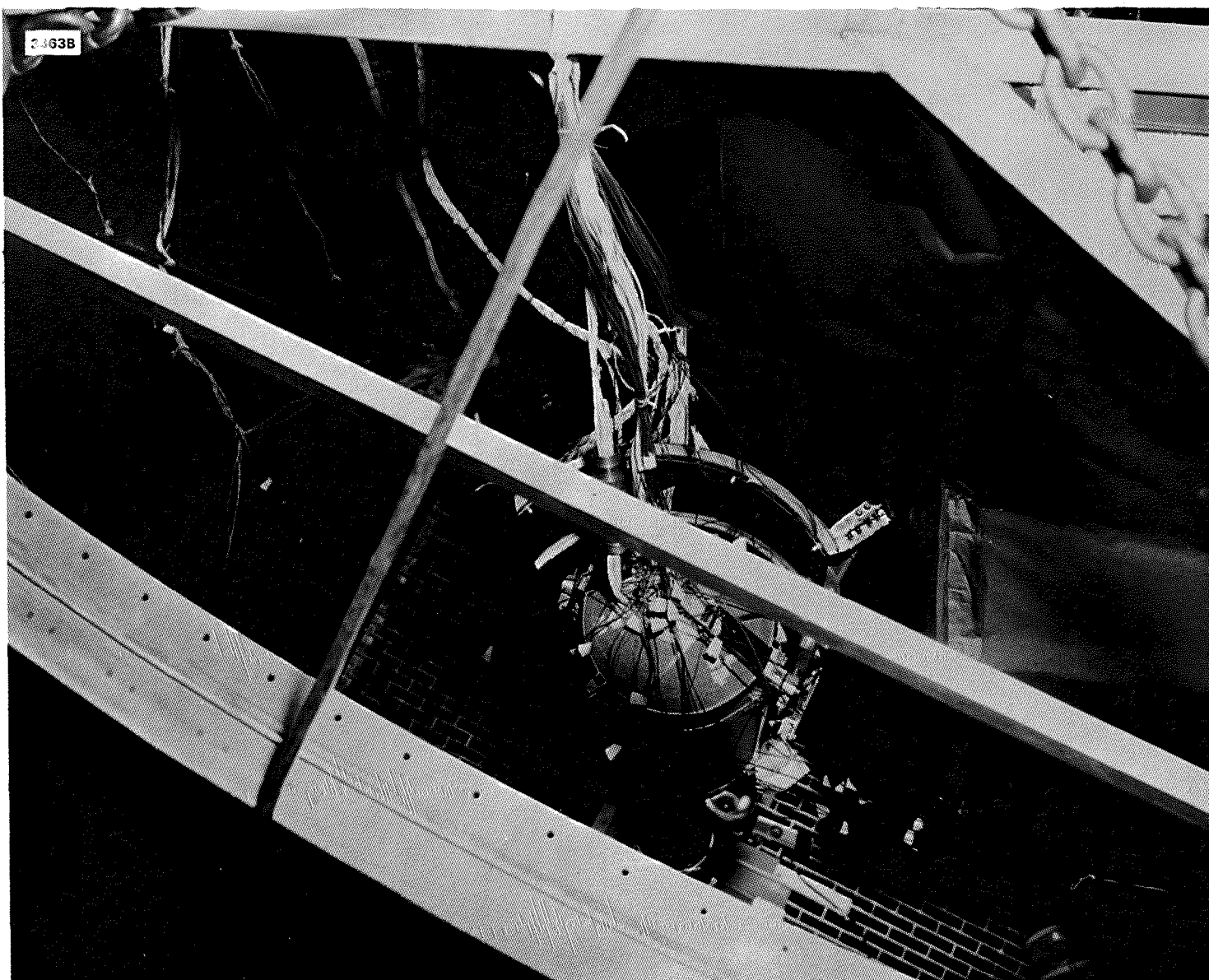


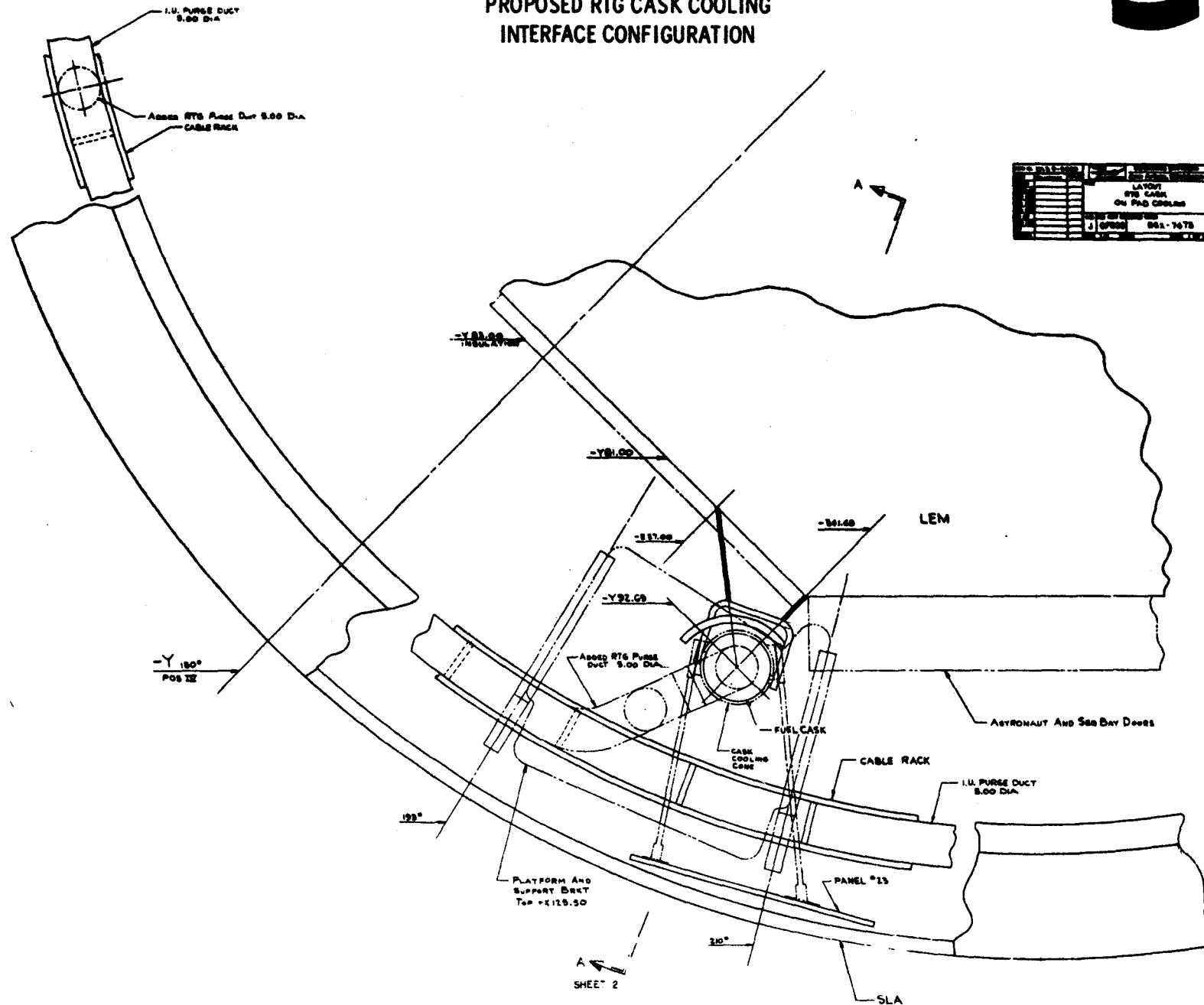
Figure 1.6 Prototype Cask and Conical Nozzle Configuration (Viewed From Above)

[illegible]

Figure 1.7 RTG Cask Cooling Nozzle Locations for BxA Prototype Test Program

Figure 1.8

PROPOSED RTG CASK COOLING  
INTERFACE CONFIGURATION



SHEET 2

5607-43

From the relative sequencing of the pre-launch cask loading and hydrogen fuel tank loading, it would appear that the temperature of this reduced flow would always be near ambient rather than the 130°F temperature which is later used to maintain instrument temperature in the IU section. However, since the requirement to reduce to total SLA flow rate for personnel comfort had not been established, the reduced mass flow tests were carried out with both 75°F and 130°F supply air as a conservative measure.

Although not specifically a part of the prototype cask cooling test, a discussion section (4.0) has been included which covers some of the interface problems which have arisen during the cask cooling system development. In detail these problems consider nozzle integration with the IU duct, the temperature rise inside the SLA during cask cooling with heated GN<sub>2</sub>, the temperature decay along the IU duct, etc.

## 2.0 THERMAL ANALYSIS AND CORRELATION

The prediction of the maximum cask surface temperature was based on a correlation of the open side surface temperatures on the cask plus a correlation of the maximum cask surface temperature relative to the maximum open side surface temperature. The actual details of this procedure were covered in ATM #763, but for convenience, a synopsis of the procedure is included here.

It was found in the original cask cooling test that the measured local velocities and surface temperatures could be correlated very well by a single formula as:

$$T_s - T_{amb} = \frac{1050}{u_e^{0.71}}$$

This form applied equally well over the entire cylindrical surface of the cask. However the only place where the surface velocities could be reliably predicted was on the open (i. e., unobstructed) side of the cask. Therefore on this open side of the cask, the velocity, and thus surface temperature, could be related to the location, size, flowrate, and pressure differential of the particular nozzle in use. Further, the maximum surface temperature was found to be essentially ten percent higher than the maximum open side surface temperature in °F. (This maximum is located approximately 2/3 of the way up the cylinder.) Consequently the maximum cask surface temperature can be related to the nozzle and its supply parameters as:



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 15           | OF 42    |
| DATE 15 July 1968 |          |

For conical nozzles the velocity is:

$$u_e = \frac{77 \cos \theta \sqrt{\dot{m} \Delta p}^{1/4}}{x + 2.7 \sqrt{\dot{m} / \Delta p}^{1/4}}$$

For plugged nozzles the velocity is:

$$u_e = \frac{57 \sqrt{\dot{m} \Delta p}^{1/4}}{x + 1.9 \sqrt{\dot{m} / \Delta p}^{1/4}}$$

And the velocity is related to the surface temperature as:

$$\Delta T = \frac{1050}{u_e^{0.71}}$$

where

$u_e$  = surface velocity ~ fps

$\dot{m}$  = mass flow ~ lb/sec

$\Delta p$  = pressure differential ~ psf

$x$  = distance from nozzle exit to point on cask barrel ~ ft

$\theta$  = angle between nozzle and cask axis

$\Delta T = T_{\text{surface}} - T_{\text{ambient}} \sim ^\circ\text{F}$

Thus the maximum surface temperature would be

$$T_{\text{max}} \approx 1.1 (T_{\text{amb}} + T_{x=x_{\text{max}}})$$



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |              |
|-------------------|--------------|
| NO.               | REV. NO.     |
| ATM-764           |              |
| PAGE <u>16</u>    | OF <u>42</u> |
| DATE 15 July 1968 |              |

The above formulas were developed for cooling by a jet of ambient temperature air. When the jet is heated, some adjustment must be made for the mixing (entrainment) of the heated jet and the lower-temperature surrounding air. Further, this ambient temperature will increase with time if it is confined and recirculated as may be the case for cask cooling within the SLA.

The temperature distribution in a heated jet has been well established by such works as that of reference 2. In that paper, the ratio of the temperature differences between the local jet and ambient and the initial jet and ambient is found to be a unique function of the number of nozzle diameters downstream. In Figure 2.1 this result is plotted for the test conditions of a 130° jet exhausting into 75° air. For the plugged nozzle, an effective nozzle diameter equal to the nozzle gap would be a reasonable assumption - so that this curve could be used with plugged nozzles as well.

In Table I, a synopsis of the various cooling configurations and test operating conditions are given. Also given are the predicted and measured values of the velocity and temperature at the furthest instrumented point downstream on the open side of the cylindrical portion of the cask. According to the results of the previous cask cooling test, the maximum cask surface temperature should be approximately ten percent higher than these maximum open side surface temperatures. This result is compared for the prototype test in the last two columns of Table I.

The relatively minor discrepancies which exist in this table may be attributed to two basic sources. The first source is from the apparent breakdown of the cask internal re-entry shield in regard to uniformity of heat transfer. As may be seen in Figure 2.2 through 2.8, even after disqualification of some of the thermocouple readings, the temperature distributions on the cask surface during cooling are not at all uniform. Although the cooling drops as the flow proceeds up the cask and is not uniform around the cask, the resulting surface temperatures of the first test still maintained a smooth, though varying, distribution. The main difference in the cask configuration between this test and the previous GE engineering model (BCTA) is that the cask of the first test did not have an inner shield. Therefore the highly discontinuous surface temperature distributions on the prototype cask must be attributed to the non-uniform behavior in the conductivity of the accompanying inner shield. Further, because of this non-uniformity, it is to be expected that the individual deviations from a mean correlation would be larger than that of the previous test. Thus in some local regions, the prototype cask surface temperatures exceeded the values as predicted from the initial cooling test correlations.



TABLE I  
SUMMARY OF PROTOTYPE CASK COOLING TEST RESULTS

| Run No. | Nozzle Size-in <sup>2</sup> | Nozzle Position Below Cask | Mass Flow Lb/Min. | Flow Temperature | Supply Pressure-psig | Vel. at Cyl. End |         | Temp. at Cyl. End |       | Max. Surf. Temp |       | Location of Meas(all on Upper port. of cylinder | Maximum Velocity (FPM) 1 Ft above cask | Cask Surface Temperature Range, °F |
|---------|-----------------------------|----------------------------|-------------------|------------------|----------------------|------------------|---------|-------------------|-------|-----------------|-------|---|--|------------------------------------|
|         |                             |                            |                   |                  |                      | Pred.            | Meas.   | Pred              | Meas. | Pred.           | Meas. |   |  |                                    |
| 1       | 4.0                         | 24"                        | 10                | 130°F            | .05                  | 770 fpm          | 650 fpm | 267°F             | 262°F | 290°F           | 286°F | Left  | 500                                    | 181-286                            |
| 2       | 4.0                         | 24"                        | 17                | 130°             | .15                  | 1300             | 1500    | 209               | 205   | 230             | 234   | Left  | 1200                                   | 142-234                            |
| 3       | 4.0                         | 24"                        | 17"               | 75°              | .15                  | 1300             | 1500    | 193               | 198   | 212             | 222   | Left  | 1250                                   | 130-222                            |
| 4       | 4.0                         | 24"(off 2"lft)             | 17"               | 130°             | .15                  | --               | 500     | --                | 233   | --              | 253   | Front   | 1800                                   | 135-253                            |
| 5       | 4.0                         | 24"(off 2"rt)              | 17                | 130°             | .15                  | --               | 1300    | --                | 225   | --              | 253   | Left  | 1150                                   | 155-254                            |
| 37      | 4.0                         | 24"(2"off rt)              | 17                | 130°             | .15                  | --               | 2200    | --                | 186   | --              | 246   | Right *   | 1100                                   | 138-245                            |
| 38      | 4.0                         | 24"(off 2" lft)            | 17                | 130°             | .15                  | --               | 1250    | --                | 209   | --              | 262   | Right *   | 1000                                   | 126-262                            |
| 6       | 4.0                         | 24"at 18°                  | 10                | 130°             | .05                  | 740              | 950     | 269               | 241   | 295             | 302   | Left  | 500                                    | 103-301                            |
| 7       | 4.0                         | 24"at 18°                  | 17                | 130°             | .15                  | 1310             | 1800    | 215               | 190   | 236             | 249   | Left  | 1000                                   | 152-248                            |
| 8       | 4.0                         | 24"at 18°                  | 17                | 75°              | .15                  | 1310             | 1800    | 199               | 180   | 236             | 239   | Left  | 1000                                   | 137-238                            |
| 9       | 4.0                         | 36"at 18°                  | 10                | 130°             | .05                  | 620              | 950     | 288               | 258   | 316             | 308   | Left  | 300                                    | 102-308                            |
| 10      | 4.0                         | 36"                        | 17                | 130°             | .15                  | 1050             | 1800    | 224               | 203   | 247             | 253   | Left  | 500                                    | 96-253                             |
| 11      | 4.0                         | 36"                        | 17                | 75°              | .15                  | 1050             | 1500    | 213               | 195   | 234             | 244   | Left  | 1200                                   | 160-244                            |
| 12      | 4.0                         | 36"(off 2"lft)             | 17                | 130°             | .15                  | 1050             | 1300    | --                | 218   | 247             | 244   | Left  | 600                                    | 159-244                            |
| 13      | 4.0                         | 36"(off 2"rt)              | 17                | 130°             | .15                  | 1050             | 1200    | --                | 205   | 247             | 268   | Left  | 800                                    | 169-268                            |
| 14      | 4.0                         | 15"at 28°                  | 10                | 130°             | .05                  | 330              | 600     | 260               | 265   | 285             | 295   | Left  | 500                                    | 106-295                            |
| 15      | 4.0                         | 15"at 28°                  | 17                | 130°             | .15                  | 1420             | 1100    | 207               | 212   | 227             | 247   | Left  | 700                                    | 158-247                            |
| 16      | 4.0                         | 15"at 28°                  | 17                | 75°              | .15                  | 1230             | 950     | 187               | 205   | 206             | 237   | Left  | 600                                    | 138-237                            |
| 17      | 6.0                         | 24"                        | 21                | 130°             | .09                  | 1330             | 1400    | 215               | 205   | 232             | 255   | Right *   | 800                                    | 100-255                            |
| 18      | 6.0                         | 24"                        | 21                | 75°              | .09                  | 1330             | 1300    | 192               | 196   | 215             | 238   | Right *   | 800                                    | 152-239                            |
| 19      | 6.0                         | 24"                        | 27                | 130°             | .17                  | 1600             | 2200    | 193               | 182   | 211             | 225   | Right *   | 1200                                   | 119-225                            |
| 20      | 6.0                         | 24"at 18°                  | 27                | 130°             | .17                  | 1520             | 2100    | 199               | 183   | 216             | 228   | Left  | 1300                                   | 122-228                            |
| 21      | 6.0                         | 24"at 18°                  | 21                | 75°              | .09                  | 1250             | 1250    | 198               | 204   | 219             | 243   | Right *   | 700                                    | 108-243                            |
| 22      | 6.0                         | 24"at 18°                  | 21                | 130°             | .09                  | 1250             | 1250    | 222               | 214   | 235             | 255   | Right *   | 700                                    | 128-255                            |
| 23      | 6.0                         | 36"                        | 21                | 130°             | .09                  | 1000             | 1200    | 230               | 222   | 247             | 257   | Left  | 600                                    | 133-257                            |
| 24      | 6.0                         | 36"                        | 21                | 75°              | .09                  | 1000             | 1200    | 219               | 213   | 234             | 244   | Left  | 600                                    | 136-244                            |
| 25      | 6.0                         | 36"                        | 27                | 130°             | .17                  | 1300             | 1700    | 206               | 195   | 214             | 224   | Left  | 1100                                   | 124-229                            |
| 29      | 3.6 Plugged                 | 24"                        | 15                | 130°             | .18                  | 850              | 600     | 237               | 256   | 274             | 298   | Right *   | 400                                    | 123-298                            |
| 30      | 3.6 Plugged                 | 24"                        | 15                | 75°              | .18                  | 85               | 600     | 233               | 252   | 256             | 293   | Left  | 400                                    | 112-293                            |
| 31      | 3.6 Plugged                 | 36"                        | 15                | 130°             | .18                  | 680              | 500     | 264               | 269   | 300             | 314   | Left  | 300                                    | 125-313                            |
| 32      | 3.6 Plugged                 | 36"                        | 15                | 75°              | .18                  | 680              | 500     | 262               | 264   | 288             | 311   | Left  | 300                                    | 114-311                            |
| 33      | 5.9 Plugged                 | 36"                        | 18                | 130°             | .09                  | 640              | 750     | 268               | 260   | 305             | 309   | Right *   | 300                                    | 131-309                            |
| 34      | 5.9 Plugged                 | 36"                        | 18                | 75°              | .09                  | 640              | 750     | 266               | 255   | 292             | 303   | Right *   | 300                                    | 112-303                            |
| 35      | 5.9 Plugged                 | 24"                        | 18                | 130°             | .09                  | 800              | 800     | 248               | 248   | 284             | 298   | Left  | 450                                    | 207-299                            |
| 36      | 5.9 Plugged                 | 24"                        | 18                | 75°              | .09                  | 800              | 800     | 242               | 242   | 206             | 290   | Left  | 450                                    | 122-290                            |

\*The upper right T/C was not reading accurately so these temperatures are based on the middle right T/C

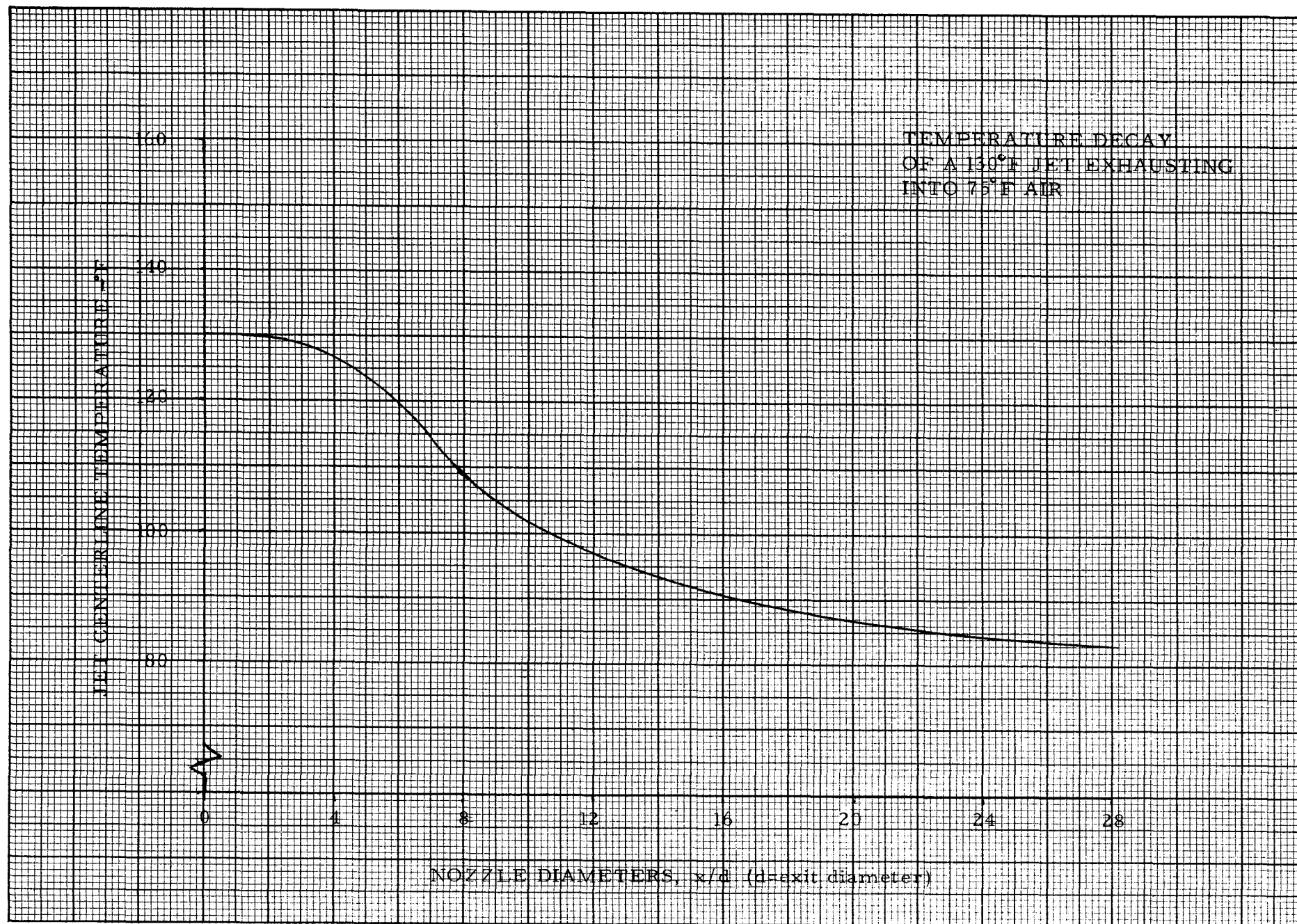
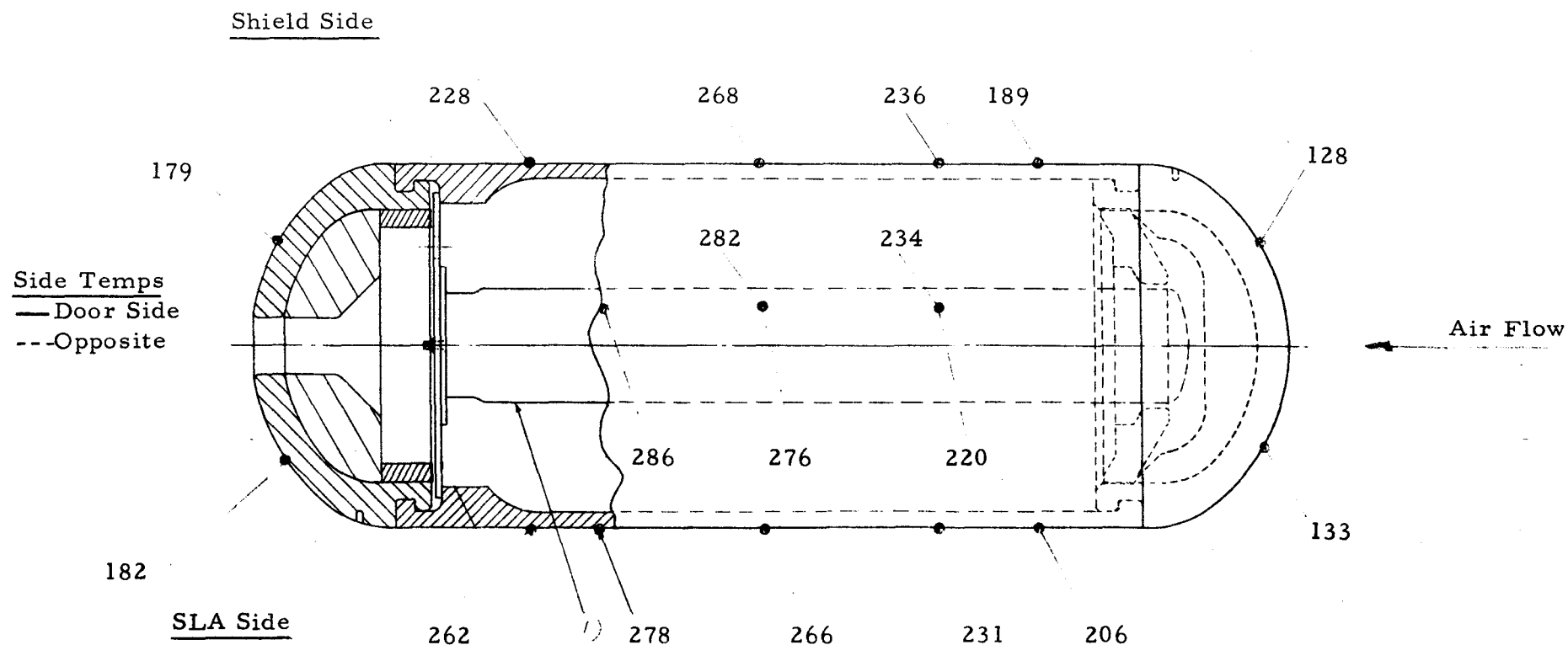


Figure 2.1 Temperature Decay of a 130°F Jet Exhausting into 75°F Air

Run no. 1  
 2.25 in dia. Conical Nozzle  
 24 in. separation



Surface Description

Test Results °F

|                          |             |
|--------------------------|-------------|
| 1. Capsule Surface       | 1101 - 1262 |
| 2. Cask External Surface |             |
| a. Center                | 182 - 286   |
| b. Ends                  | 189 - 262   |
| 3. Cask Domes            | 128 - 185   |
| 4. Thermal Shield        | 82 - 93     |
| 5. Astronaut Door        | 76 - 213    |
| 6. LM Panel              | 73 - 83     |
| 7. SLA                   | 70 - 72     |
| 8. Air Supply            | 130         |

Figure 2.2 On Pad Forced Cooling Test Cask Surface Temperature Results 10 lb/min of 130°F Air

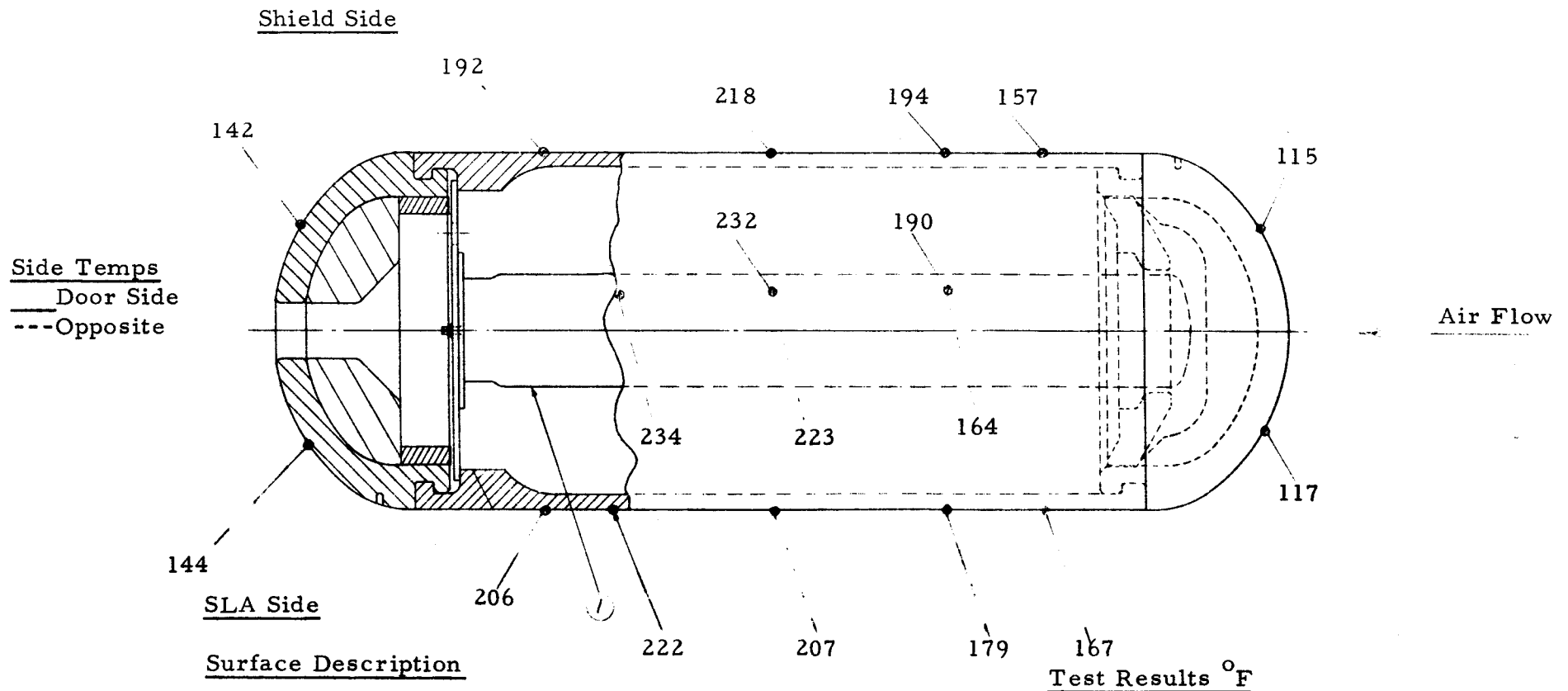
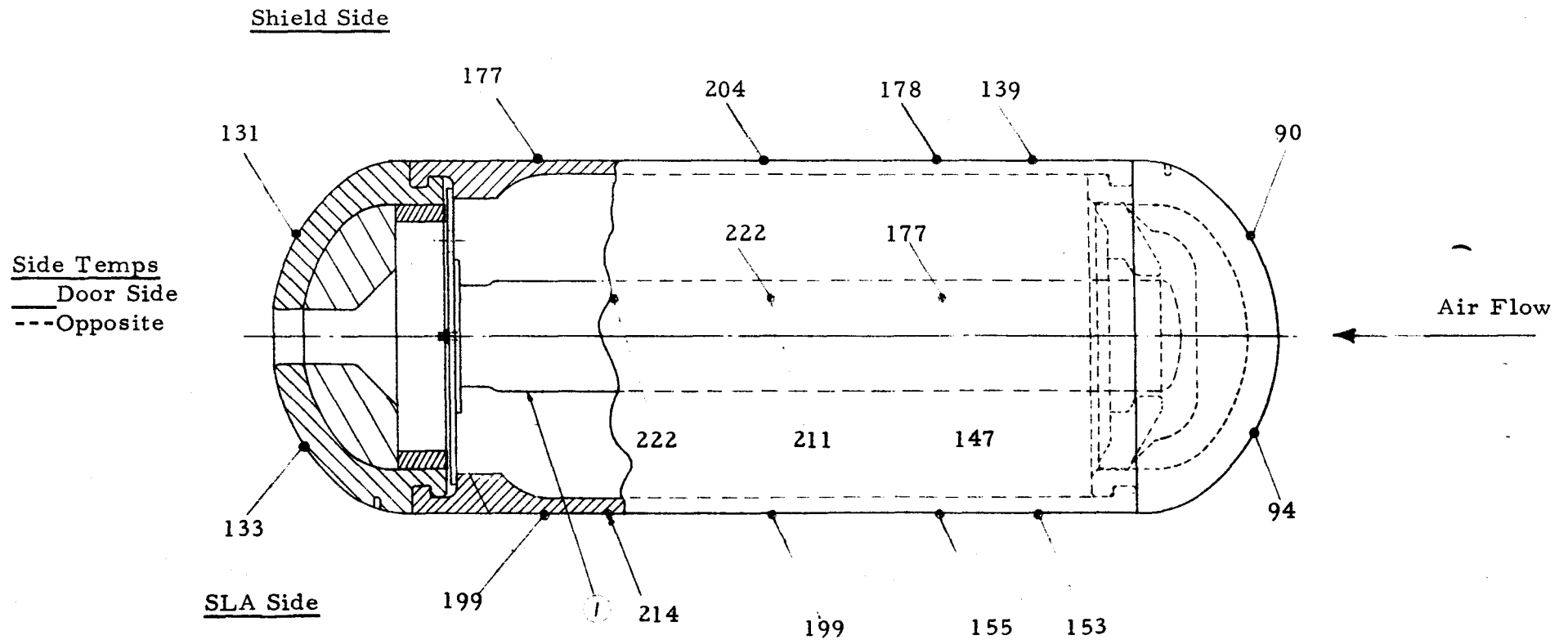


Figure 2.3 On Pad Forced Cooling Test Cask Surface Temperature Results 17 lb/min of 130°F Air



Surface Description

1. Capsule Surface
2. Cask External Surface
  - a. Center
  - b. Ends
3. Cask Domes
4. Thermal Shield
5. Astronaut Door
6. LM Panel
7. SLA
8. Air Supply

Test Results °F

1090 - 1256

131 - 222

139 - 199

170 - 133

71 - 95

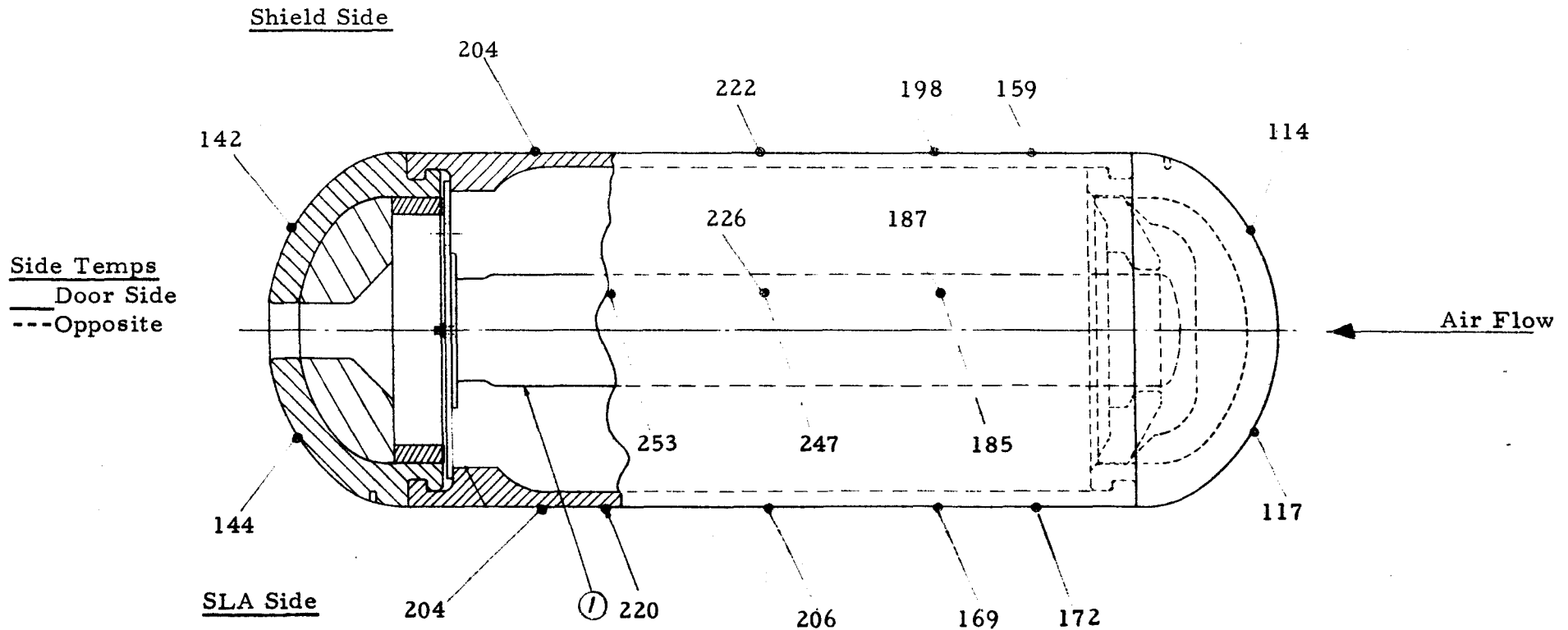
72 - 211

71 - 75

71 - 72

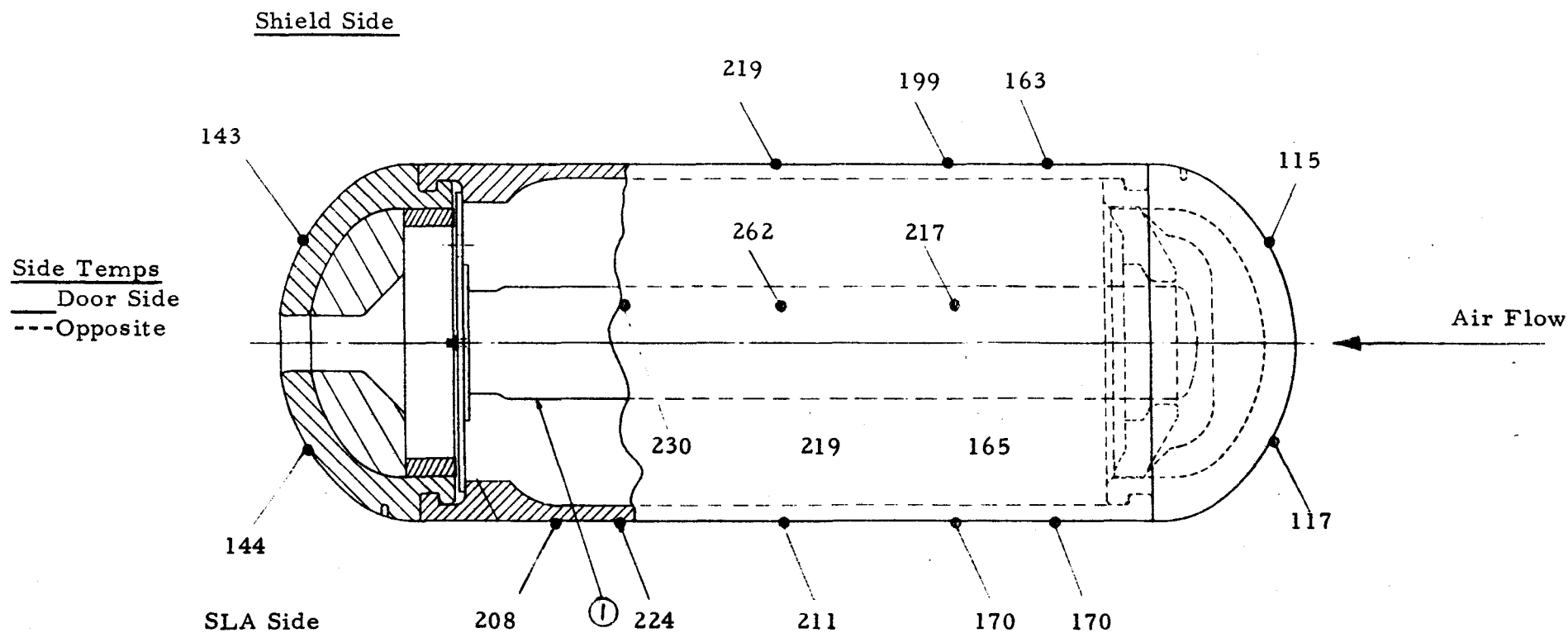
75

Figure 2.4 On Pad Forced Cooling Test Cask Surface Temperature Results 17 lb/min of 75°F Air



| <u>Surface Description</u> | <u>Test Results °F</u> |
|----------------------------|------------------------|
| 1. Capsule Surface         | 1094 - 1257            |
| 2. Cask External Surface   |                        |
| a. Center                  | 155 - 253              |
| b. Ends                    | 159 - 204              |
| 3. Cask Domes              | 114 - 144              |
| 4. Thermal Shield          | 82 - 93                |
| 5. Astronaut Door          | 74 - 212               |
| 6. LM Panel                | 73 - 80                |
| 7. SLA                     | 72 - 73                |
| 8. Air Supply              | 130                    |

Figure 2.5 On Pad Forced Cooling Test Cask Surface Temperature Results 17 lb/min of 130°F Air-Nozzle Offset to Right

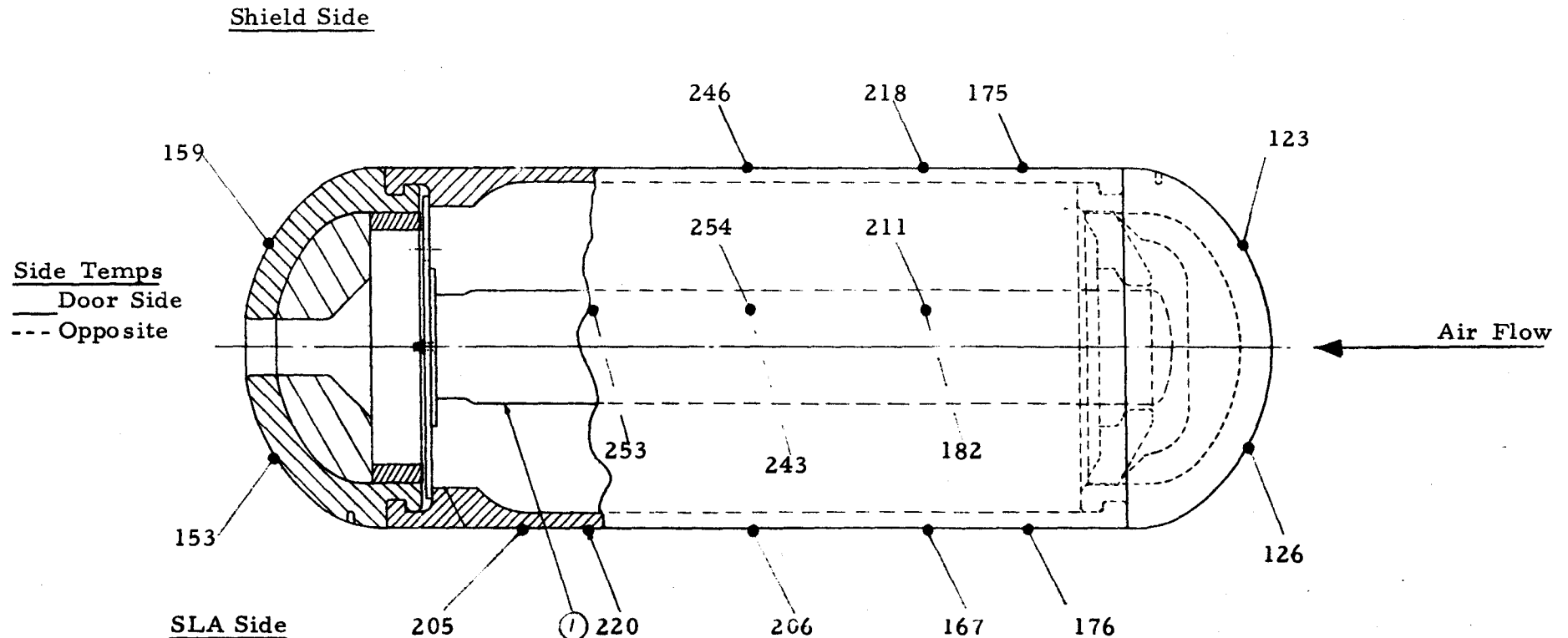


Surface Description

Test Results °F

|                          |             |
|--------------------------|-------------|
| 1. Capsule Surface       | 1097 - 1257 |
| 2. Cask External Surface |             |
| a. Center                | 183 - 230   |
| b. Ends                  | 127 - 208   |
| 3. Cask Domes            | 115 - 144   |
| 4. Thermal Shield        | 84 - 96     |
| 5. Astronaut Door        | 75 - 284    |
| 6. LM Panel              | 75 - 79     |
| 7. SLA                   | 73 - 74     |
| 8. Air Supply            | 130         |

Figure 2.6 On Pad Forced Cooling Test Cask Surface Temperature Results - 17 lb/min of 130°F Air  
 Nozzle Offset to Left



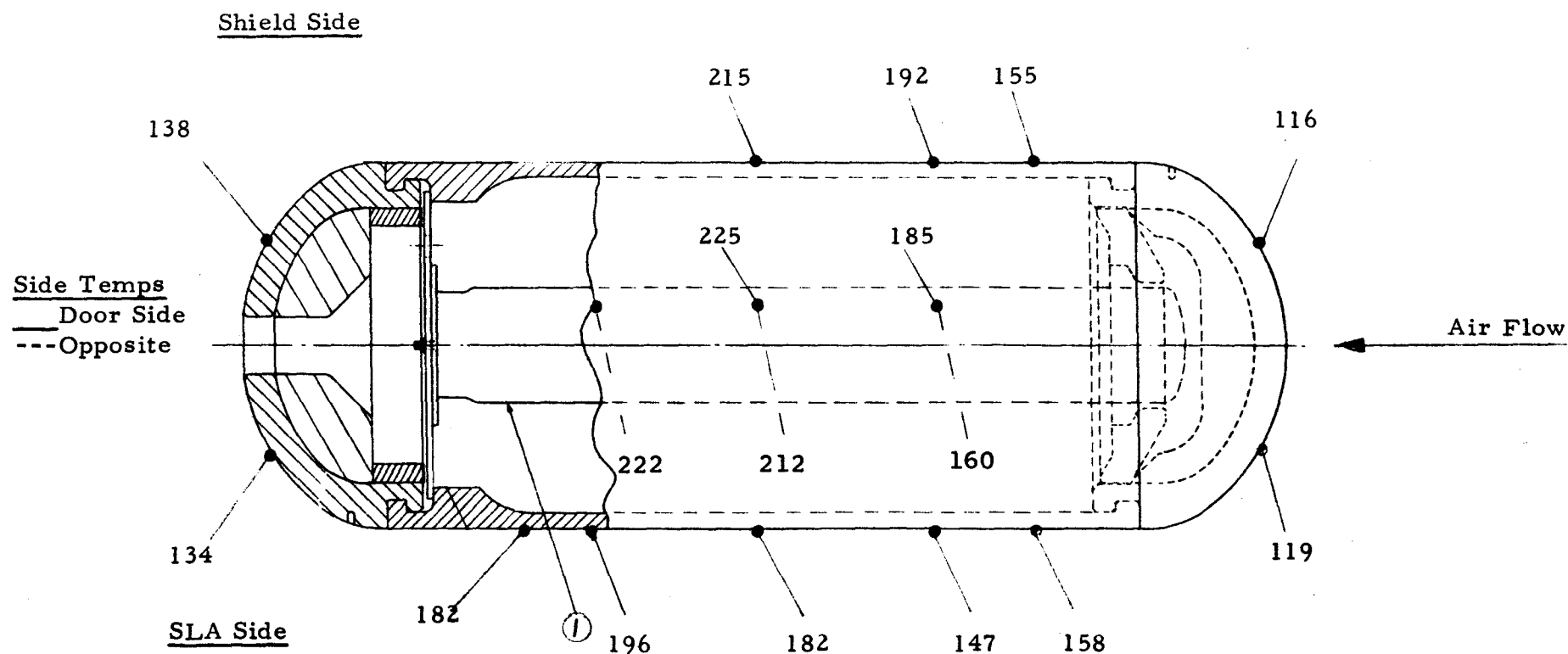
Surface Description

Test Results °F

|                          |             |
|--------------------------|-------------|
| 1. Capsule Surface       | 1098 - 1258 |
| 2. Cask External Surface |             |
| a. Center                | 174 - 254   |
| b. Ends                  | 101 - 205   |
| 3. Cask Domes            | 123 - 159   |
| 4. Thermal Shield        | 85 - 94     |
| 5. Astronaut Door        | 76 - 282    |
| 6. LM Panel              | 72 - 81     |
| 7. SLA                   | 73 - 75     |
| 8. Air Supply            | 130         |

Figure 2.7 On Pad Forced Cooling Test Cask Surface Temperature Results 22 lb/min of 130°F Air





Surface Description

Test Results °F

|                          |             |
|--------------------------|-------------|
| 1. Capsule Surface       | 1094 - 1255 |
| 2. Cask External Surface |             |
| a. Center                | 153 - 225   |
| b. Ends                  | 119 - 158   |
| 3. Cask Domes            | 116 - 138   |
| 4. Thermal Shield        | 81 - 93     |
| 5. Astronaut Door        | 75 - 276    |
| 6. LM Panel              | 74 - 79     |
| 7. SLA                   | 73 - 74     |
| 8. Air Supply            | 130         |

Figure 2.8 On Pad Forced Cooling Test Cask Surface Temperature Results 27 lb/min of 130°F Air



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 26           | OF 42    |
| DATE 15 July 1968 |          |

The second source of discrepancy between the predicted and measured surface temperatures lies in the surface velocity predictions (Table I). While no attempt was made to predict the velocity variations which would occur from the misalignment of the nozzle (runs 4, 5, 37, and 38), even in the aligned cases the quality of the velocity predictions was sometimes marginal. The basic reason for this occasional disagreement lies in the deviation from the geometry of the original correlations as made in the first set of cooling tests.

In the first cask cooling tests, November 1967, the majority of velocity data correlation was performed on the various forms of the plugged nozzle. When placed relatively close to the cask, this type of nozzle has an advantage over the conical nozzle in that there is only a minor disruption of the flow pattern by the cask. Thus at close range, the basic flow from a plugged nozzle can be predicted relatively well from the classical theories of two dimensional flow exhausting into open air.

On the other hand the characteristic flow diameter of a conical nozzle placed relatively close to the cask is much smaller than the cask itself. Thus the jet pattern must be highly distorted as the flow impinges at the bottom of the cask and subsequently flows up the side of it. Accompanying this flow distortion are marked variations in the pressure distribution and in the corresponding velocity pattern. The reason that this problem was not encountered in the previous tests is that the few conical nozzles that were tested were placed at a relatively large distance from the cask. Thus by the time the cooling air had reached the cask, the jet had spread out considerably and had subsequently entrained a large amount of additional air. Therefore the cask behaved as if it were in a uniform flow rather than having a discreet jet impinge upon it. Consequently although flow distortions similar to those of the closely placed conical nozzle did exist, they were relatively minor.

Another problem which arises with the close placement of a conical nozzle and the cask is the sensitivity to the manner in which the flow is diverted around the cask. Even a slight off center placement of the nozzle or non-uniformity of the flow can cause more flow to go around one side of the cask than the other - thereby modifying the cooling distribution as in runs 4, 5, 37, and 38 versus run 2.

Consequently the above results merely serve to reinforce one of the conclusions of the original ATM 763, i. e., that for remote placement, a conical nozzle is more efficient in cask cooling and for close placement, a plugged nozzle is more efficient. (As had been noted, the plugged nozzle



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 27           | OF 42    |
| DATE 15 July 1968 |          |

decreases in cooling effectiveness with increasing distance from the cask because the inside edge of the flow eventually merges - thereby resulting in markedly increased dissipative losses.)

The nozzle misalignment tolerance has now been specified as a maximum of 0.5 inches off the Cask/Nozzle centerline, plus a maximum of 2.0 degrees angular misalignment. These values were not in effect at the time of testing so 2.0 inch offset was used as an outside limit. This offset is greater than would occur with the current tolerances and the nozzle 24 inches below the cask. Also at that distance, no problem should be anticipated from replacing an angular misalignment with a linear displacement.

In spite of the relatively large nozzle misalignment and the subsequently disproportionate distribution of cooling air around the cask, the net effect of a 2.0 inch nozzle misalignment only caused approximately a 30 degree temperature increase with 17 lb/min of cooling air. However, the real concern was not over the disproportionate distribution of air, but over the possibility of large scale flow separation in the region of reduced air flow. The left side of the trunnions are especially susceptible to this type of separation. From the measured velocity data, it does not appear that such separation took place to any large extent on these tests. Nonetheless such possibilities must be considered for any variation in the cask cooling system - regardless of how small that variation might seem. Consequently a nozzle offset for both high and low mass flows is being planned for the qualification cask cooling test series at GE.

As the velocity above the cask is of interest from an interference standpoint, the velocity of the cooling flow one foot above the cask was measured and is tabulated in Table I. These values are in accordance with some previous internal experimental work that established the velocity above the cask as a function of the mass flow and the downstream distance (Figure 2.9).

Another velocity which is of some interest is the velocity around the cask mounting structure and over the SLA and LM walls. In the original cask cooling test, no simulated walls were in place. Thus no velocity measurements of this sort could be taken. However it was determined that the velocity was essentially negligible at a distance of three inches or more away from the sides of the cask.

In the prototype cask cooling test, a cannister was used to simulate the vehicle walls (see Figure 1.5). This cannister was somewhat overly restrictive in that side panels were used instead of the fully open circumferential spacing of the actual vehicle. Irrespective of the side paneling, the

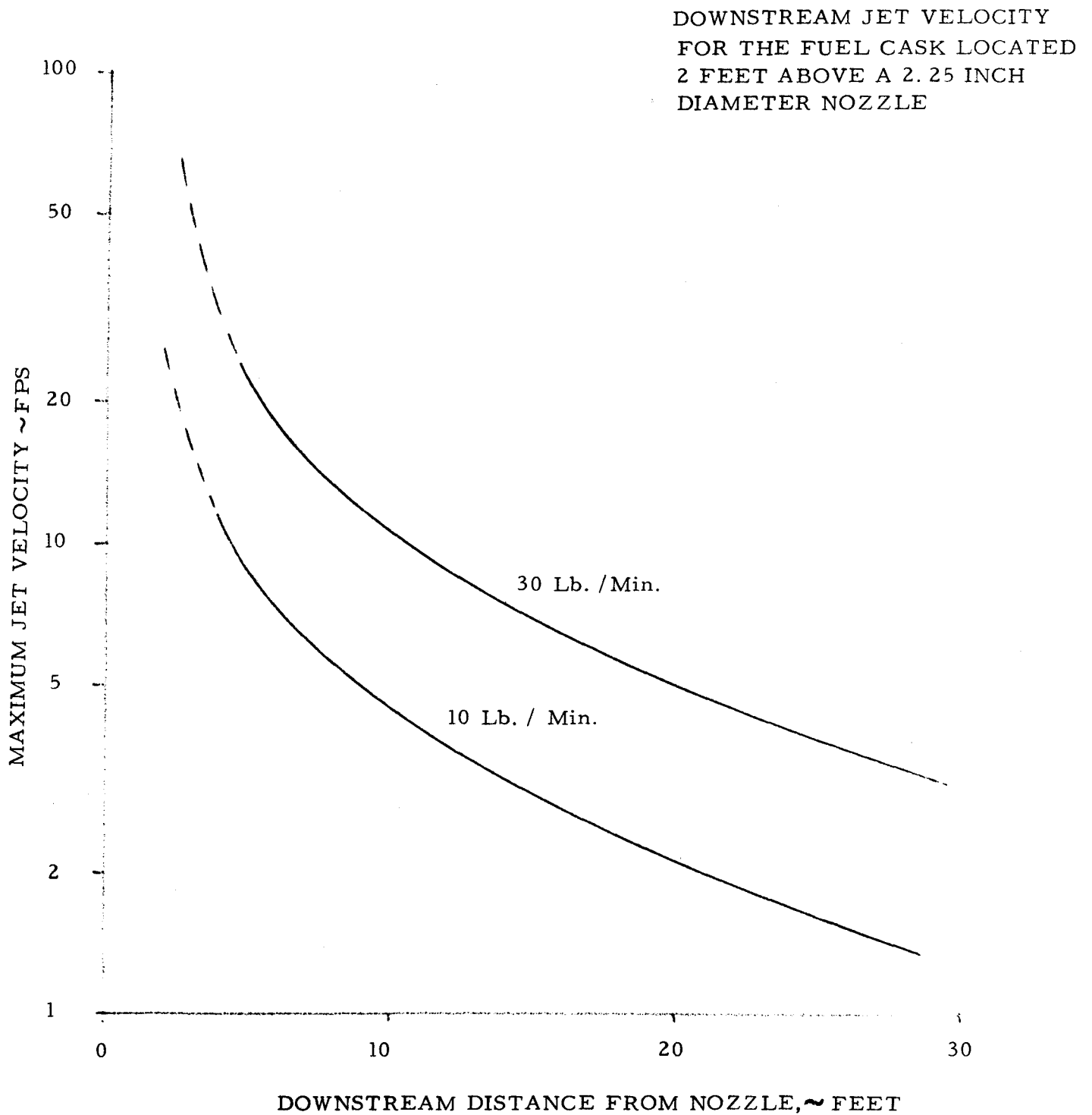


Figure 2.9 Downstream Jet Velocity for the Fuel Cask Located 2 Feet  
Above a 2.25 Inch Diameter Nozzle



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 29           | OF 42    |
| DATE 15 July 1968 |          |

net result of the canister influence from a flow standpoint is to introduce a type of chimney effect. This effect is a consequence of the flow entrainment by the basic cooling jet and will be similar in the actual operational vehicle.

Flow measurements were taken throughout the cannister during the cask cooling tests, and in no case did the flow velocity reach even one foot per second except in the aforementioned immediate vicinity of the cask.

One further measurement of interest is the resultant cask surface temperature rise in the event that the cask cooling should be discontinued for one reason or another. For this purpose, two transient temperature measurements were made from different cooling levels. In Figure 2.10 the maximum surface temperature is plotted as a function of elapsed time after shutdown of the cooling system. As may be seen, the surface temperature rise for the first minute is approximately 40°F per minute, and thereafter the surface temperature rise is of the order of 15-25°F per minute - up to the maximum free convection surface temperature of approximately 650°F.

### 3.0 CONCLUSIONS

From a cask cooling standpoint, the basic objectives of this test were:

1. To verify the correlations of the first cooling test as applied to the somewhat different geometry and nozzles of the prototype test.
2. To extend the correlations of the first cooling test to include effects of nozzle misalignment and heated air (including the flow above the cask).
3. To determine what effects, if any, might be incurred from the more bulky, flight, cask mounting hardware as opposed to the simplified cask mounting hardware at the first test.

In regard to these objectives, the results of the prototype tests were quite satisfactory. The uniformity of the cask surface temperature data and the consistency of the cooling velocity data do leave something to be desired, but as long as the deviations are adequately explicable, then there is no great cause for concern, i. e. : The non-uniformity of the cask surface temperatures on the cylinder appear to be largely a result of localized conductivity breakdowns in the cask internal re-entry liner, plus a slight over-extension of the original cooling velocity correlations.

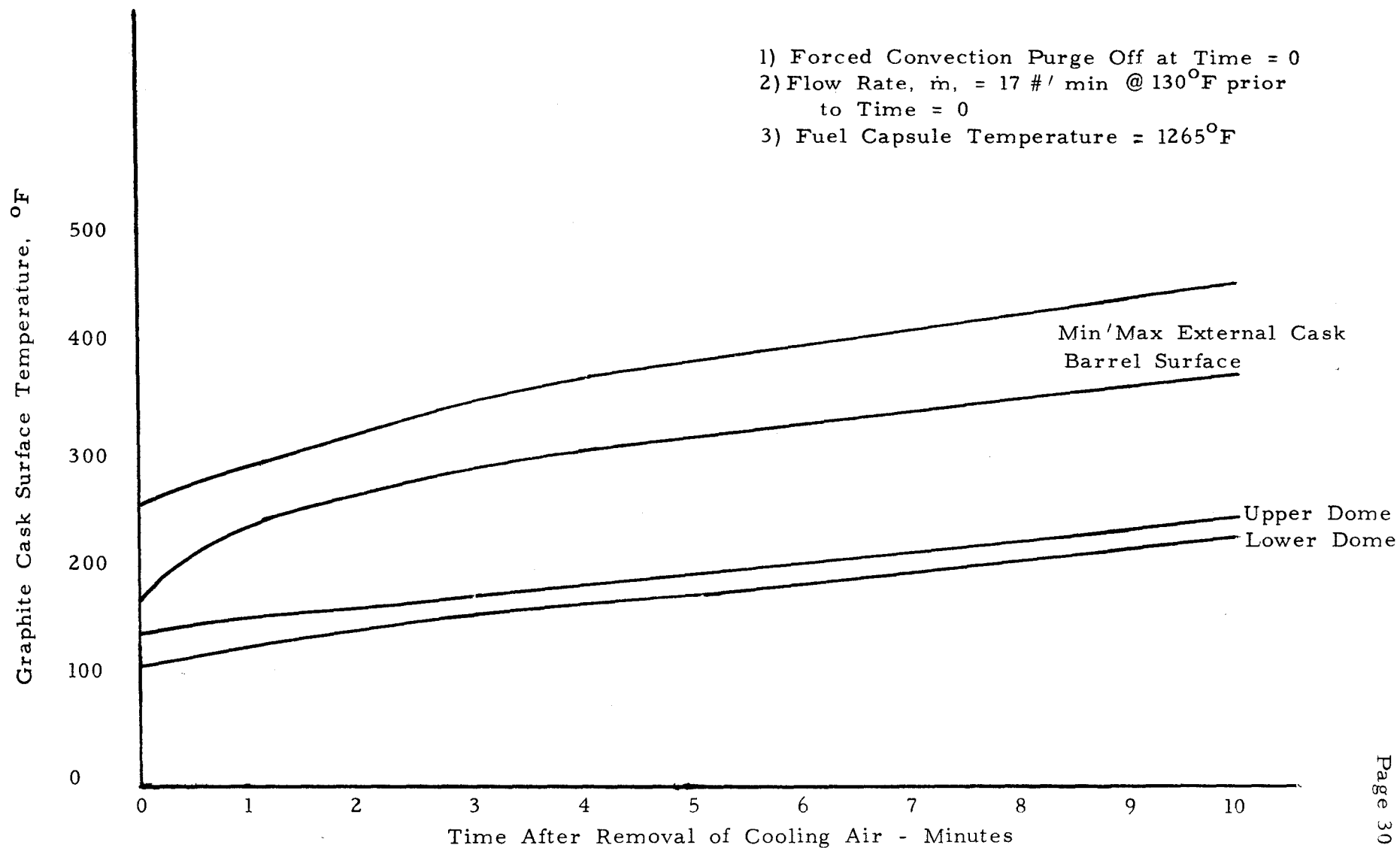


Figure 2.10 GLFC Surface Transient Temperature Rise



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

NO. ATM-764

REV. NO.

PAGE 31 OF 42

DATE 15 July 1968

#### 4.0 DISCUSSION

##### 4.1 ALSEP RTG Cask Cooling System Interface Considerations - Cooling Nozzle Size and Air/GN<sub>2</sub> Supply Requirements

As the RTG cask cooling nozzle is a part of the IU cooling system, the sizing of this nozzle is inseparably tied to the overall IU system performance. That is, since there are no controls between the IU duct and the cask cooling nozzle, the relative amount of cooling flow which goes out of the IU orifices and the cask cooling nozzle is proportional to the ratio of the effective exhaust areas.

Assuming that the range of total flowrates is given, and that a maximum allowable cask surface temperature is specified, there is still a variety of nozzles which will satisfy the basic cask cooling requirement. Further, because of the relatively small amount of flow taken from the IU system by the cooling nozzle, a considerable latitude in this nozzle design is allowed without significantly affecting the IU performance. Therefore additional factors may be incorporated in the determination of the most satisfactory design compromise.

One of these factors would be the alignment problem between the nozzle and the cask. Current estimates place the LM alignment within the SLA at approximately  $\pm 1$  inch. As the nozzle mount will be fixed relative to the SLA and the cask will be fixed relative to the LM, this 1 inch tolerance must also be placed on the cask and cooling nozzle alignment.

From geometric considerations, a larger area (and subsequently a larger mass flow) nozzle would be less sensitive to misalignment. In Figure 4.1, an extended set of nozzle designs (per ATM-763) are overlaid on the MSFC IU performance results (ref. 4). The temperatures which accompany these nozzles include a 15% allowance resulting from a potential nozzle misalignment of two inches. Note that the lines of constant temperature are nearly parallel to the lines of constant total flow. Thus at a fixed total flow, a variation in the nozzle size will alter the amount of flow tapoff for cask cooling, but does not significantly alter the resultant surface temperature. Therefore for a particular nozzle location, the cask surface temperature maybe said to be a function of the total flow rate to the IU environmental conditioning duct - and is independent of the nozzle size.

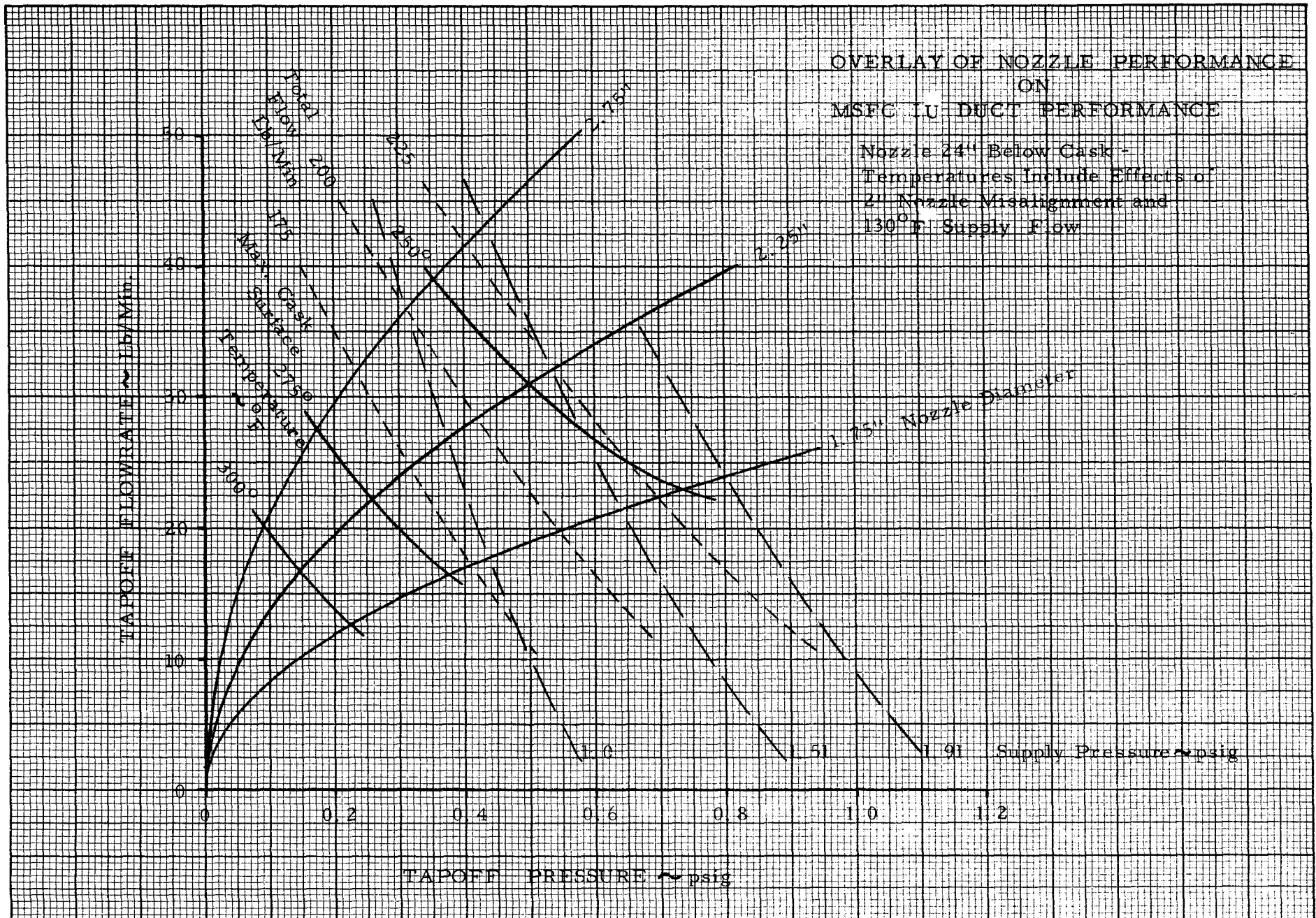


Figure 4.1 Overlay of Nozzle Performance on MSFC IU Duct Performance





**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 33           | OF 42    |
| DATE 15 July 1968 |          |

In view of the above statement, a larger area nozzle would better handle the misalignment problem - providing no other detrimental effects are introduced by increasing the nozzle size. The portion of mass flow being taken away from the IU cooling/heating system does not appear to be excessive - and thus this factor should not play a dominant role in nozzle selection. Another factor of interest in the cask cooling problem is the resulting heated exhaust plume above the cask. This jet is flowing in opposition to a 95 pound/minute 75°F cooling flow coming from a more forward position on the vehicle (Figure 4.2). As the initial IU flow may be heated to as much as 130°F for a period of up to 16 hours, the cask cooling jet may pour a considerable amount of heat into the forward region of the vehicle. Consequently the forward penetration of the cask cooling jet and its total heat content (including the RTG heat output) could be a significant factor in the nozzle selection.

At present the 130°F maximum air/GN<sub>2</sub> temperature applies to the incoming flow. Therefore it is in order to estimate the probable temperature drop through the IU duct plus the ductwork leading to the cooling nozzle.

Although the flow rate in the IU duct may not always be high enough to maintain turbulent flow, the heat transfer to the inside walls will nonetheless be at a sufficient level such that the heat loss to the system will be governed by the essentially free convection heat loss of the outer surface. That is, it may be assumed that there is always sufficient heat available at the inner duct wall and thus the net heat flow will be controlled by the rate at which it can be convected away by the ambient air.

The formulation of this problem leads to a first order, linear differential equation which, upon solution, yields an exponential decay of the difference between the duct flow temperature and the ambient temperature. The solution must be applied piecewise between the individual holes in the IU duct, and at each hole readjusted for the new mass flow and reference temperature. In Figure 4.3, two typical solutions are given. Within the assumption of the free convection level on the outside of the duct, these solutions represent the maximum temperature drop which might be anticipated. In reality, as the 130°F cask cooling air returns and/or recirculates, the ambient temperature will exceed the initial 75°F temperature - thereby decreasing the temperature drop in the IU and cask nozzle ductwork.

Consequently because of the relatively small duct temperature decay, it must be assumed that the cask cooling jet may be pouring air/GN<sub>2</sub> at a temperature of 130°F. Further, because the time constant for this condition may be quite large, (T-8 hours plus), it is possible that a condition of equilibrium may be reached or at least approached in the forward selection of the vehicle.

The basic configuration is that of a heated jet blowing over a heated cask, and then up the interior of the vehicle against a purging flow of approximately 95 pounds per minute at 75°F. The exhaust system for these

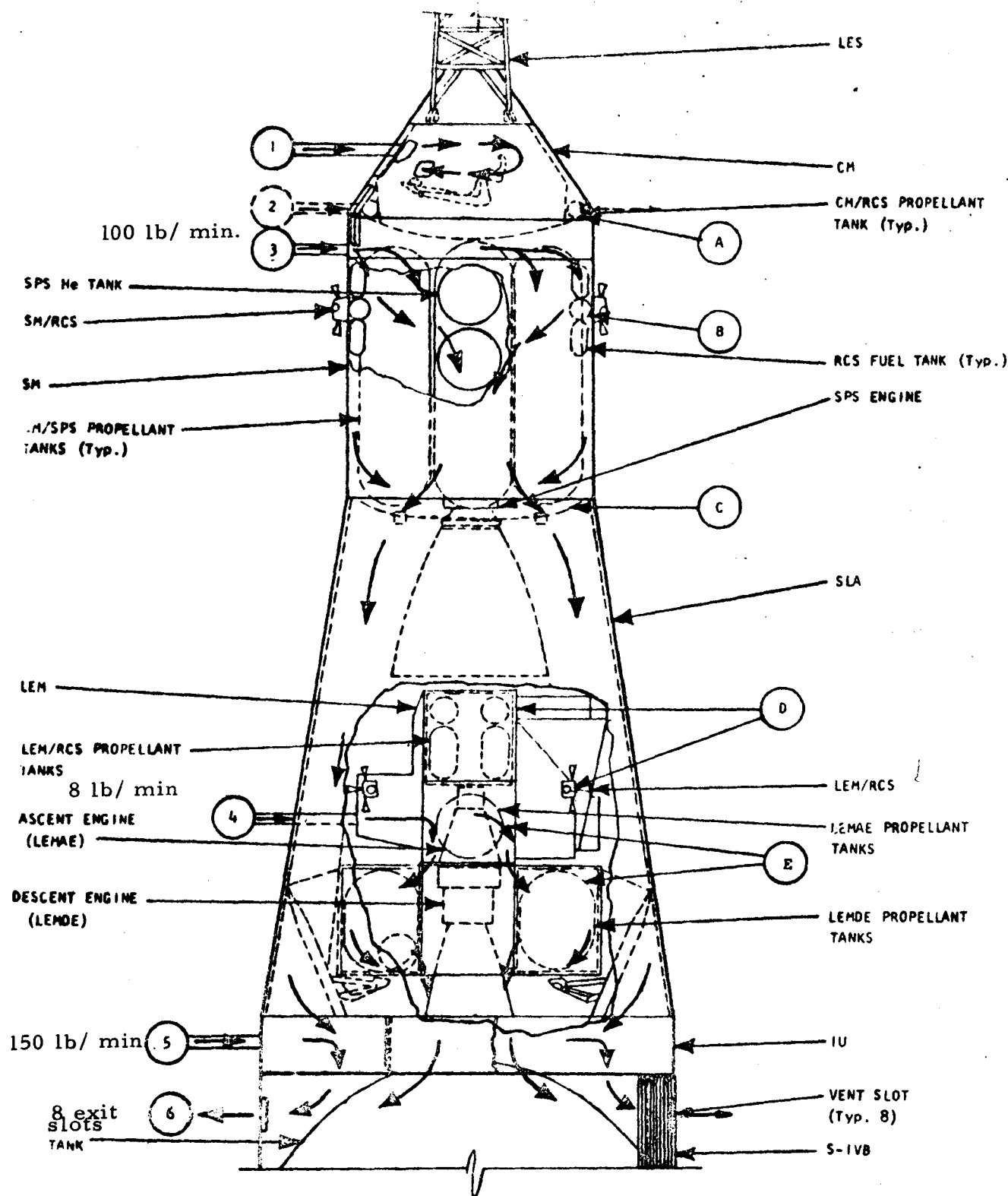


Figure 4.2 Physical Configuration of CSM/LEM/SLA - Block 11

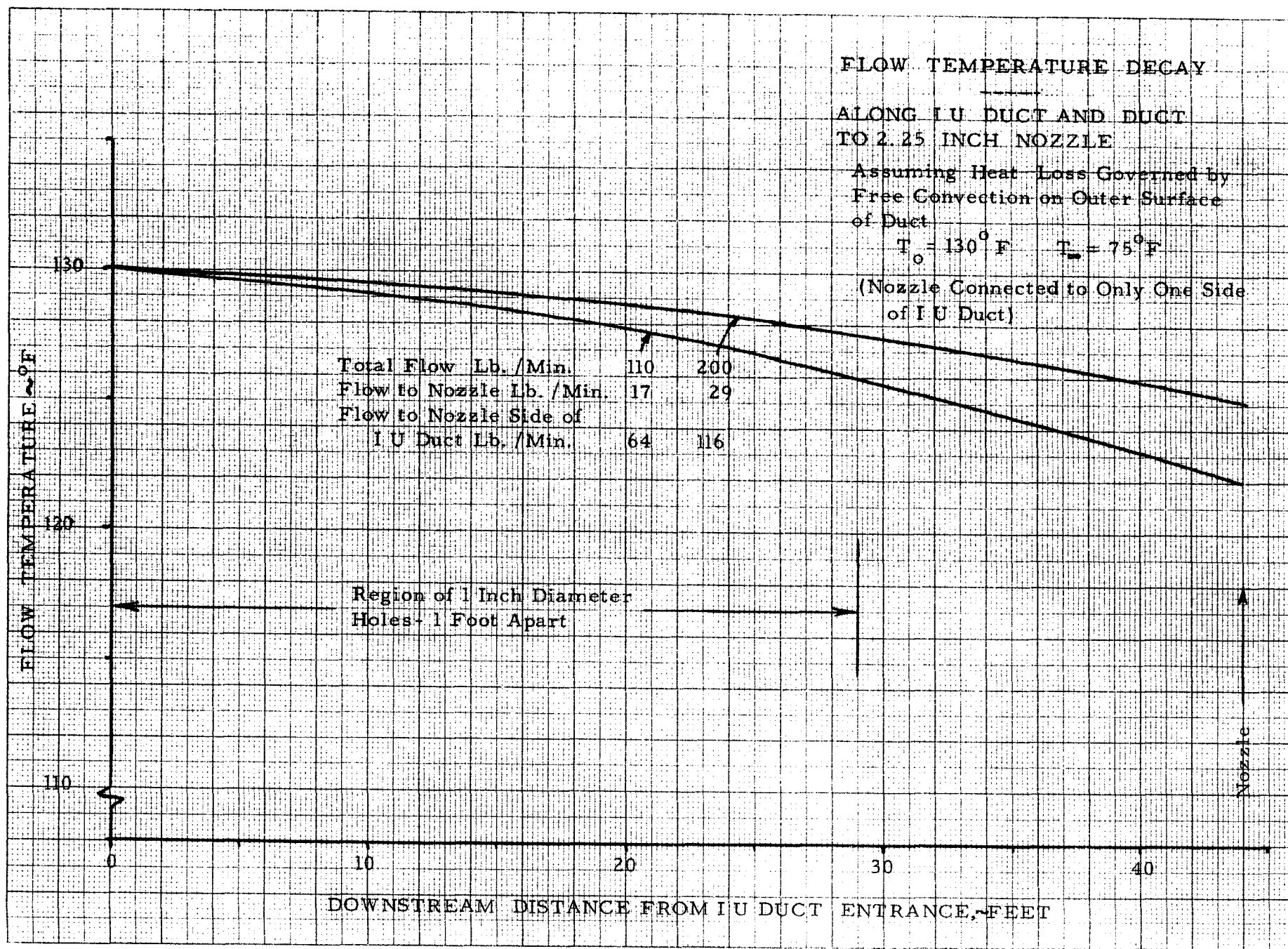


Figure 4.3 Flow Temperature Decay



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 36           | OF 42    |
| DATE 15 July 1968 |          |

gases is located below the nozzle so that the jet flow must eventually reverse its direction and be discharged below its point of origin.

Although it is not possible to analytically predict the flow temperatures and velocities inside the SLA during cask cooling, it is possible to make certain statements about the bounds of the values which might be anticipated. As will be shown, the idealized case of a free jet which entrains ambient air is not totally applicable, nor is the assumption of total mixing of the cask cooling jet and the forward cooling air.

The velocity and temperature distributions in a free turbulent jet have been well established on a semi-empirical basis and these solutions are common in the open literature (ref. 2). However because of the presence of the cask in the jet flow and because of the constraintment of the SLA upon that flow, the free jet solutions are not applicable in this case. In Figure 2.9 and 4.4, estimated values of the velocity and temperature distributions are given along with the equivalent free jet values. Also given are the total mass flows as a function of downstream distance. This total mass flow is made up from the basic jet flow plus that which is entrained as the flow precedes downstream.

In order to estimate the values of the velocity above the cask, a series of tests were run with and without the cask in front of the nozzle. The free jet cases agreed quite well with the classical values so that the interference cases were also considered to be valid.

As may be noted in Figure 4.4, the net mass flow directed upward considerably exceeds the actual mass flow being exhausted from that area of the vehicle. What this difference actually means is that there will be a good deal of recirculation of the flow inside the SLA - especially at the higher mass flows of the cooling nozzle. That is, the effective time constant of the jet flow is small enough so that the entrained flow may recirculate to make many trips with the jet in the course of a minute - and thus even in the constrained flow within the SLA, the flow entrainment may approach that of a free jet.

Since the basic mechanism for the temperature decay in a heated jet is the flow entrainment of the lower temperature ambient air, a restriction of the mass entrainment will result in a decrease in the decay of the jet temperature. Thus the jet temperature inside the SLA will be maintained at a higher level than it would be in an open flow situation. Consequently the temperatures above the cask as measured in the two cask cooling tests to date will be lower than would be expected inside the SLA.

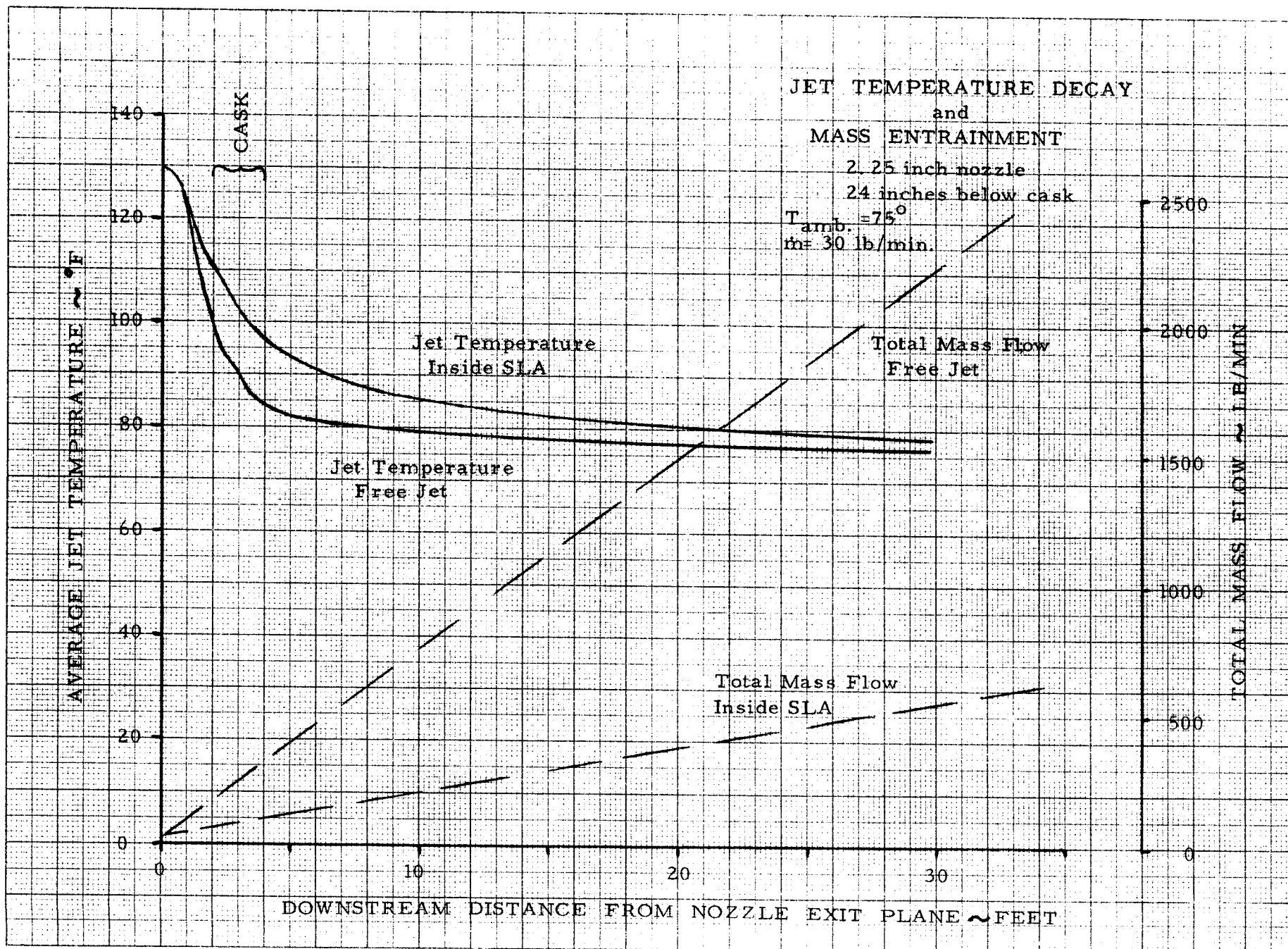


Figure 4.4 Jet Temperature Decay and Mass Entrainment



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 38           | OF 42    |
| DATE 15 July 1968 |          |

The above comments are pertinent to the initial period of the jet heating where no appreciable heat transfer to the ambient air has taken place. However, because of the high degree of mixing between the cask jet and the upper cooling flow, it may be anticipated that some averaging of the two temperatures will quickly occur. In Figure 4.5 the adiabatic equilibrium temperatures are given for various levels of mixing. It is rather unlikely that total mixing would ever occur since this would require the jet to completely disperse over a region simulated by two concentric truncated cones with a wall separation distance of the order of two feet and a diameter of the order of 15 feet. For a rough estimate of the mixing (i. e., entrainment level) the flow may be considered to be geometrically modified so that the expansion takes place in only one dimension that is, between essentially parallel plates. This limit will reduce the mass flow by a factor of 2 squared or 4. These reduced values of flow entrainment are given in Figure 4.4 along with the free jet values.

As a check on the levels of mass entrainment of Figure 4.4, it may be noted from Figure 2.9 that the average centerline velocity of the 30 pound per minute jet is of the order of 5-10 feet per second over the 20 odd feet above the nozzle. Thus the effective time constant for a recirculating flow is of the order of 5-10 seconds for a full cycle. Therefore on a full minute basis, approximately 5-10 cycles/min will be completed. If 95/4 pounds per minute plus 30 pounds per minute are involved in this recycling, then on a minute basis, approximately 250 to 500 pounds per minute may be entrained. Consequently the reduced entrainment of Figure 4.4 lies in the proper range. Further a mixing factor in the range from 0.25 to 0.50 appears to be an appropriate value. Note, however, that the temperature levels of Figure 4.5 are for an adiabatic situation (i. e., no heat transfer to the surrounding walls, etc.) so they represent a maximum level. In reality the heat capacity of the vehicle will reduce this temperature somewhat. Also the actual heat transfer to the vehicle as a result of this temperature rise is not at a very significant level. Such a conclusion has also been reached by Grumman (Ref. 3) who conducted an analysis to determine if the heating effects of the cask cooling system would be detrimental to the somewhat narrow temperature limits on the LM fuel tanks. Therefore although the flow temperatures in the region above the cask may eventually reach the higher values of Figure 4.5, the temperatures of the non-adiabatic regions in the vicinity of the walls will be nearer to the wall temperature and in any event, the net heat transfer to the relatively high capacity vehicle will be small as compared to solar radiation, etc.

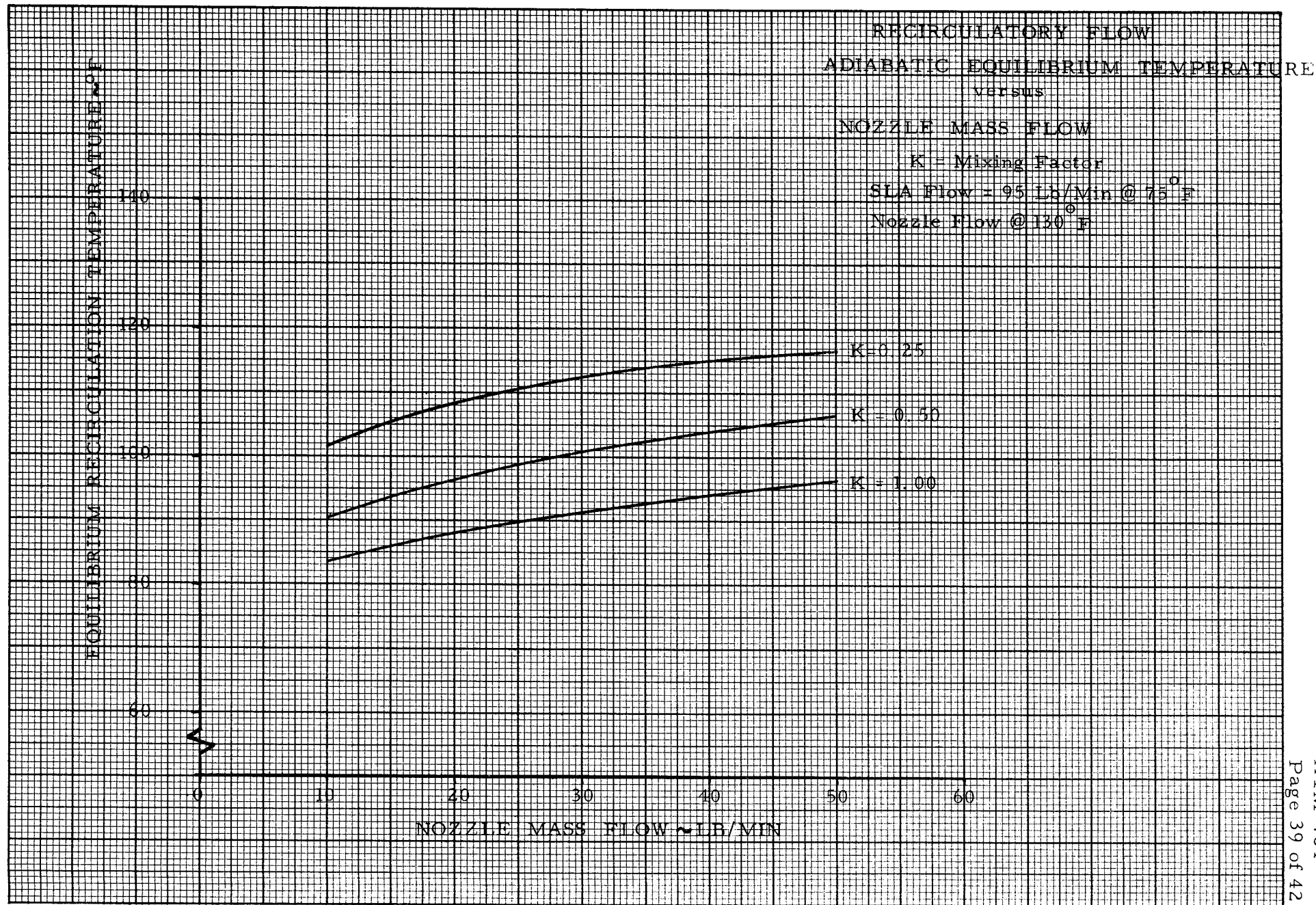


Figure 4.5 Recirculatory Flow Adiabatic Equilibrium Temperature





**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 40           | OF 42    |
| DATE 15 July 1968 |          |

While the above comments indicate that the upper LM heating by the cask cooling system is not critical, it would be well to minimize the long term net heat input to this section of the vehicle. As the main source of heat is from the heated flow rather than the fuel capsule, minimizing the heat input would indicate a minimal flow rate. Further, since the pressure supply levels will be fixed by the IU flow requirements, the only other way to minimize the flow rate is to reduce the nozzle exit area. This reduction also has the advantage of reducing the net flow of momentum, thereby lowering the forward velocity penetration. Although no limits have been set upon this velocity, it is possible that too high a velocity could disrupt such things as LM insulation, etc.

Consequently only two factors appears to be significant in the problem of selecting a cooling nozzle. One is the alignment problem which would dictate a larger area nozzle (and thus higher mass flow), and the other is the forward flow temperature, which, at least for the near-equilibrium case would dictate a smaller mass flow (and thus smaller nozzle area).

From the results of the prototype cask cooling test, a two inch nozzle offset toward the left cask trunnion resulted in a maximum surface temperature increase of approximately 30°F using a 2.25 inch diameter nozzle with a flowrate of 17 pounds per minute - and approximately a 20°F increase from nozzle offsets in the other three directions. As the positioning of the LM inside the SLA presently has a tolerance of approximately  $\pm 1$  inch, the relative positioning of the cask and nozzle may well approach 2.0 inches in axial misalignment. Therefore, the test offset is a realistic one.

If the possibility of a two inch nozzle misalignment must be accepted, then care must be taken so as not to reduce the nozzle diameter too much. From flow measurements taken on the cask surface during the offset tests, it appears that the flow on the side opposite the nozzle offset was nearly marginal in terms of any effective cooling. Thus for a possible two inch nozzle offset, a 2.25 inch diameter nozzle approaches the minimum size for complete eircumferential cooling of the cask. Further, because this problem is essentially a geometrical one, a rough rule of thumb for the nozzle size is that the nozzle diameter shall be at least as large as the anticipated nozzle misalignment as projected to the base level of the fuel cask.

Consequently the minimum nozzle size will be set by the combined alignment tolerances of the fuel cask, Lunar Module and the IU support structure within the Saturn IV B. Since a minimum size is also desirable from the standpoint of minimizing the heated flow addition to the forward position of the SLA, this minimum nozzle size is also the most desirable nozzle size. Thus from the factors noted above, the 2.25 inch diameter





**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |          |
|-------------------|----------|
| NO.               | REV. NO. |
| ATM-764           |          |
| PAGE 41           | OF 42    |
| DATE 15 July 1968 |          |

nozzle appears to be a good design compromise. In addition, this size does not greatly affect the performance of the IU environmental conditioning duct and only takes approximately 25-30 lbs/min of its flow at the proposed operating conditions (Ref. 3).

Note that the nozzle diameters discussed above are actually effective nozzle diameters. However for the nozzles as designed and tested at BxA, most of the nozzle discharge coefficients were greater than 0.95 so that the actual nozzle diameter and the effective nozzle diameter are essentially equivalent. On the other hand the tests performed at MSFC used flat plate orifices which have discharge coefficients of approximately 0.62. Therefore the effective diameters are only  $\sqrt{.62}$  times the actual diameter.



**Aerospace  
Systems Division**

ALSEP Prototype Cask Cooling Tests

|                   |              |
|-------------------|--------------|
| NO.               | REV. NO.     |
| ATM-764           |              |
| PAGE <u>42</u>    | OF <u>42</u> |
| DATE 15 July 1968 |              |

REFERENCES

1. Bendix Aerospace Systems Division, "ALSEP Engineering, Graphite Cask Cooling Test," ATM 763, April 1968.
2. Corrsin, S. and Uberoi, M. S., "Further Experiments on the Flow and Heat Transfer in a Heated Turbulent Air Jet," NACA TR 998, 1950.
3. Grumman - (SLA Internal Heating Report)
4. Brown Engineering Company, "Instrument Unit (IU) Purge Duct Modifications," Technical Memorandum BECO-68-9, Technical Directive D-1-PE-032, April 1968.